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FM 1-5

INSTRUMENT FLYING AND NAVIGATION FOR ARMY AVIATORS

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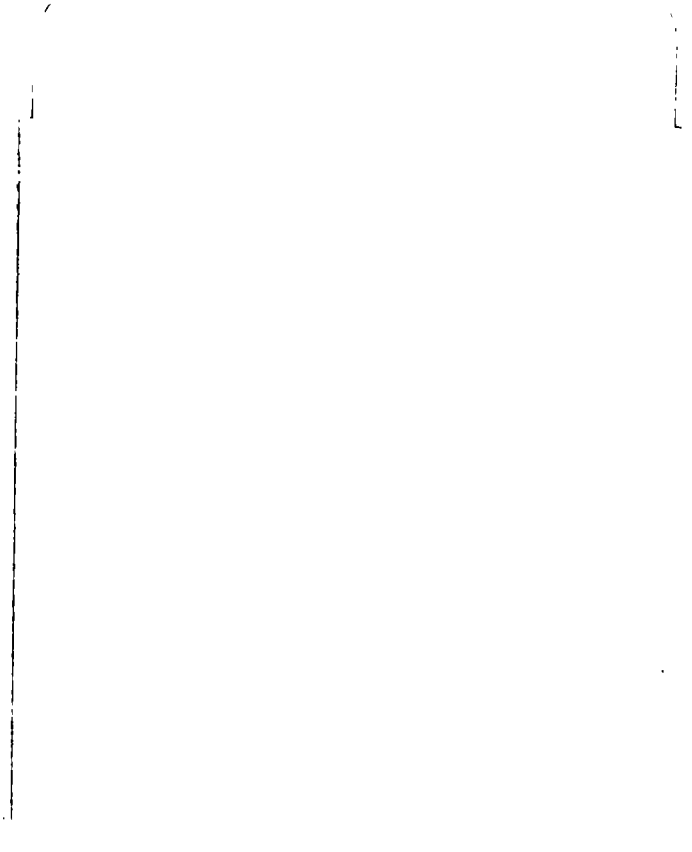

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FIELD MANUAL

No. 1-5

*FM 1-5

HEADQUARTERS
DEPARTMENT OF THE ARMY
Washington, DC, 7 July 1980

INSTRUMENT FLYING AND NAVIGATION FOR ARMY AVIATORS

CONTENTS

			Page
PART ONE.		ATTITUDE INSTRUMENT FLYING	
CHAPTER	1.	INTRODUCTION	1-1
CHAPTER	2.	FLIGHT INSTRUMENTS AND SYSTEMS	2-1
Section	I.	The Magnetic Compass	2-1
	II.	Gyroscopic Principles	2-5
	III.	Gyroscopic Instrument Power Sources	2-6
	IV.	Gyro Heading Indicator	2-7
	V.	Attitude Indicators	2-8
	VI.	Turn-and-Slip Indicator	2-12
	VII.	Slaved Gyro Compass Systems	2-14
	VIII.	The Pitot-Static System	2-17
	IX.	The Pressure Altimeter	2-19
	X.	The Airspeed Indicator	2-28
	XI.	The Vertical Speed Indicator	2-29
CHAPTER	3.	POWER, PITCH ATTITUDE, AND BANK CONTROL THROUGH INSTRUMENTS FOR FIXED AND ROTARY WING AIRCRAFT	3-1
Section	I.	General	3-1
	II.	Power Control	3-3
	III.	Pitch Attitude Control	3-6
	IV.	Bank-Attitude Control	3-12

*This manual supersedes FM 1-5, 31 March 1976, including all changes.

CONTENTS

			Page
CHAPTER	4.	BASIC INSTRUMENT MANEUVERS	4-1
Section	I.	Fixed Wing	4-1
	II.	Rotary Wing	4-15
CHAPTER	5.	PROFICIENCY MANEUVERS	5-1
PART TWO.		AIR NAVIGATION	
CHAPTER	6.	GENERAL	6-1
CHAPTER	7.	BASIC CONCEPTS OF AIR NAVIGATION	7-1
Section	I.	The Earth in Space	7-1
	II.	Measuring Position on the Earth	7-2
	III.	Measuring Direction on the Earth	7-6
CHAPTER	8.	NAVIGATION CHARTS	8-1
Section	I.	Chart Projections	8-1
	II.	Aeronautical Charts	8-9
CHAPTER	9.	PLOTTING AND MEASURING	9-1
CHAPTER	10.	INSTRUMENTS USED FOR DEAD-RECKONING NAVIGATION	10-1
CHAPTER	11.	WIND AND ITS EFFECTS	11-1
CHAPTER	12.	THE DEAD-RECKONING (DR) COMPUTER	12-1
Section	I.	General	12-1
	II.	The Slide Rule Face	12-1
	III.	Grid Side of the DR Computer	12-15
	IV.	Wind Triangles	12-17
	V.	Wind Problems	12-18
CHAPTER	13.	RADIO PRINCIPLES	13-1
CHAPTER	14.	VHF OMNIDIRECTIONAL RANGE SYSTEM (VOR)	14-1
Section	I.	Components and Operation	14-1
	II.	Flight Procedures Using the VOR	14-8
	III.	Receiver Checks	14-24
	IV.	VOR Station Classification	14-27

CONTENTS

			Page
CHAPTER 15.		AUTOMATIC DIRECTION FINDER (ADF) AND MANUAL LOOP PROCEDURES	15-1
Section	I.	Characteristics and Components	15-1
	II.	Automatic Direction Finder Flight Procedures	15-3
	III.	Automatic Direction Finder Flight Procedures Using Relative Bearings	15-9
	IV.	Manual (Loop) Operation of the ARN-59	15-17
CHAPTER 16.		THE DOPPLER NAVIGATION SET AND COMMAND INSTRUMENT SYSTEM	16-1
Section	I.	Doppler System Description	16-1
	II.	Doppler System Operation	16-8
	III.	The Command Instrument System (CIS)	16-15
CHAPTER 17.		THE INERTIAL NAVIGATION SET AN/ASN-86	17-1
Section	I.	General	17-1
	II.	Principles of Inertial Navigation	17-2
	III.	The Operation of the AN/ASN-86 Inertial Navigation Set	17-11
CHAPTER 18.		TACTICAL AIR NAVIGATION (TACAN)	18-1
CHAPTER 19.		INTRODUCTION TO INSTRUMENT APPROACH PROCEDURES	19-1
Section	I.	Instrument Approaches	19-1
	II.	Feeder Routes/Standard Terminal Arrival Routes (STARS)	19-6
	III.	Procedure Turns	19-8
	IV.	Holding	19-14
CHAPTER 20.		VHF OMNIDIRECTIONAL RANGE (VOR) AND NONDIRECTIONAL BEACON (NDB) APPROACHES	20-1
Section	I.	Approach Charts	20-1
	II.	Typical VOR Approach	20-4
	III.	Typical NDB Approach Using Automatic Direction Finder (ADF) Procedures	20-9
CHAPTER 21.		INSTRUMENT LANDING SYSTEM (ILS)	21-1
Section	I.	General	21-1
	II.	Operation and Flight use	21-3

CONTENTS

CHAPTER 22.		RADAR	22-1
Section	I.	Air Traffic Control (ATC) Radar	22-1
	II.	Radar Air Traffic Control Procedures	22-3
	III.	Transponder Operations	22-10
	IV.	Ground Weather Radar	22-12
CHAPTER 23.		TACTICAL INSTRUMENT FLIGHT	23-1
Section	I.	General	23-1
	II.	Tactical Employment Considerations	23-2
	III.	Tactical Instrument Flight Planning	23-10
	IV.	Training	23-35
APPENDIX A.		REFERENCES	A-1
	B.	AIR TRAFFIC CONTROL (ATC) SHORTHAND SYMBOLS	B-1
	C.	INSTRUMENT FLIGHT RULES (IFR) FLIGHT PLANNING	C-1
	D.	FREQUENCY MODULATED (FM) HOMING	D-1
INDEX			Index-I

STATEMENT

The words "he," "him," "his," and "men," when used in this publication, represent both the masculine and feminine genders unless specifically stated.

PART ONE

ATTITUDE INSTRUMENT FLYING

The art of controlling the performance and attitude of an aircraft by reference to instruments.

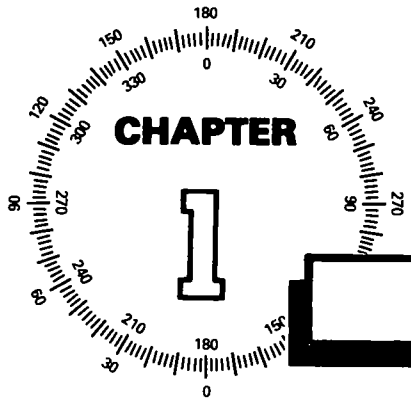
CHAPTER 1 INTRODUCTION

2 FLIGHT INSTRUMENTS AND SYSTEMS

3 POWER, PITCH ATTITUDE, AND BANK CONTROL THROUGH INSTRUMENTS FOR FIXED AND ROTARY WING AIRCRAFT

4 BASIC INSTRUMENT MANEUVERS

5 PROFICIENCY MANEUVERS



INTRODUCTION

1-1. PURPOSE

This manual provides the fundamentals, procedures, and techniques for attitude instrument flying and air navigation.

1-2. SCOPE

Part one covers the introduction and various aspects of attitude instrument flying; part two covers air navigation.

a. *Part One, Attitude Instrument Flying.* Attitude instrument flying is the art of controlling the performance and attitude of an aircraft by reference to instruments. This part covers flight instruments and their systems, a description of in-flight forces and sensations, instrument interpretation and aircraft control techniques, and procedures for the performance of fixed wing and rotary wing flight maneuvers by instruments.

b. *Part Two, Air Navigation.* Air navigation is the art of directing an aircraft along a desired course and determining its position on this course at any time. Such navigation may be by means of pilotage, dead reckoning, or radio navigational aids, and includes those procedures which are used during instrument flight in directing the aircraft to a safe landing. This part contains the following:

(1) A discussion of the basic concepts and the implements of air navigation which assist the aviator in planning and conducting a flight by means of pilotage and/or dead reckoning.

(2) Information on radio navigational aids and their employment in flight.

(3) A discussion of the facilities and procedures peculiar to instrument approaches.

1-3. COMMENTS

Users of this manual are encouraged to submit recommended changes or comments to improve it. Comments should be keyed to the specific page, paragraph, and line of the text in which changes are recommended. Reasons should be provided for each comment to insure understanding and complete evaluation. Comments should be prepared using DA Form 2028, "Recommended Changes to Publications and Blank Forms," and fowarded direct to Commander, United States Army Aviation Center and Fort Rucker, ATTN: ATZQ-TD-TL-GP, Fort Rucker, Alabama 36362.

CHAPTER 2

FLIGHT INSTRUMENTS AND SYSTEMS

Section I. THE MAGNETIC COMPASS

2-1. GENERAL

There are numerous types of heading indicators. Most are complex and require a power source for operation. The magnetic compass (fig 2-1) is simple in construction, requires no external power source, and has a high reliability factor. It uses the Earth's magnetic field to indicate the heading of the aircraft.

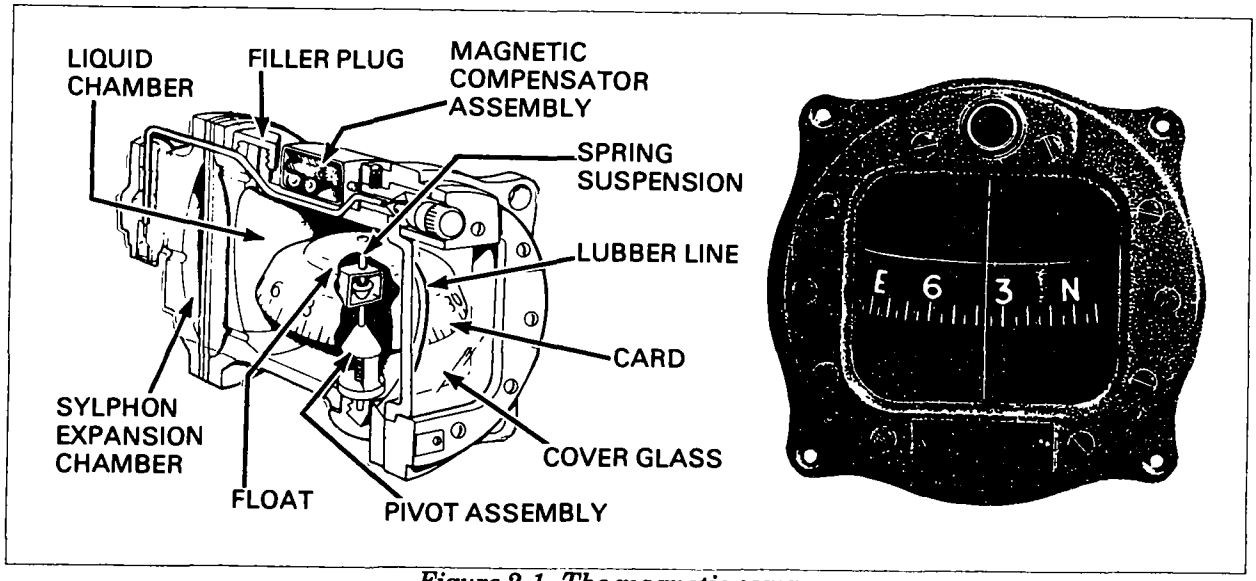


Figure 2-1. The magnetic compass.

A *magnet* is a piece of metal that has the property of attracting another metal. When freely suspended, a bar magnet will aline approximately in a north and south direction. The force of attraction is greatest at a point near the end (pole) of the magnet. Lines of force flow out from each pole in all directions, eventually bending around and returning to the other pole. The area through which these lines of force flow is called the field of the magnet. The end of the magnet that seeks north is called the North Pole.

The Earth is a magnetized body and is comparable to a huge magnet, the ends of which are several hundred miles below the Earth's surface.

a. *Location of Magnetic Poles.* The magnetic poles do not coincide with the Earth's geographic poles (fig 2-2). The approximate location of the north magnetic pole is 71° N and 96° W, and the south magnetic pole is 72° S and 157° E.

b. *Dip Angle.* The lines of force in the Earth's magnetic field are parallel to the

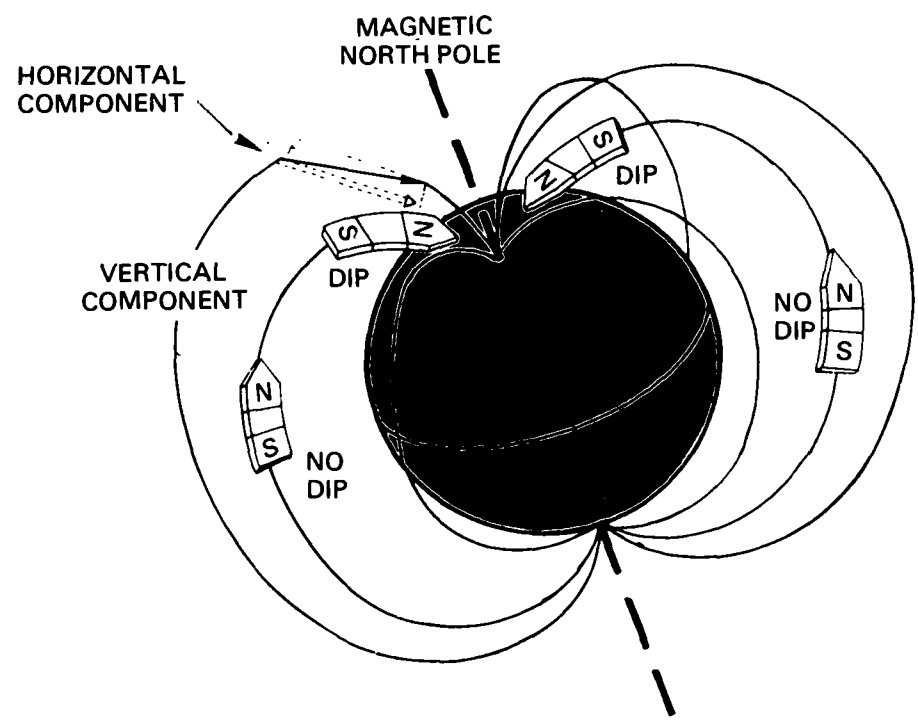


Figure 2-2. The Earth's magnetic field.

Earth's surface at the magnetic equator and they curve increasingly downward when moving closer to the magnetic poles. In general, when a magnetic needle is placed on one of the lines of force (fig 2-2), it will assume the same direction and position of the actual line of force. The Earth's magnetic field has both horizontal and vertical components (fig 2-2). Only the horizontal component is used for direction finding. If a magnetic needle is placed on a horizontal axis so that its vertical movement is free, it will dip 0° at the magnetic equator and 90° at the magnetic poles. The magnetic compass is reliable until the dip angle exceeds 84° in polar areas.

[redacted]

The compass card, which is seen through the glass window of the compass case, has letters for cardinal headings (N, S, E, and W), and numbers (with last zero omitted) at each 30-degree interval. Mounted on the float with the compass card are two magnetized needles which aline themselves (and the compass card) with the magnetic field of the Earth. The float is mounted at its center on a pedestal rising from the bottom of the compass case or bowl. The bowl is filled with kerosene. This liquid provides lubrication, rust prevention, and a dampening action on the oscillations of the compass card. Behind the glass face of the compass bowl, a vertical lubber (reference) line is mounted. The heading of the aircraft is indicated by the compass card letter or number appearing behind the lubber line. The compass also contains a compass compensating assembly which is used to adjust (or swing) the compass.

[redacted]

a. *Variation.* In some types of navigation, course computations on aeronautical charts are based upon a relation of the course to the true geographic North Pole. During flight, the magnetic compass points to the magnetic north pole, which is not at the same location as the true North Pole. This angular difference between true and magnetic north is known as *magnetic variation.* Lines of equal magnetic variation are called *isogonic lines* and are shown on aeronautical charts in degrees of variation east or west (fig 2-3). The line on a chart connecting points of 0° variation is called the *agonic line.* Lines of equal magnetic variation are replotted periodically to compensate for shifting of the poles or changes in local magnetic deposits.

b. *Deviation.* The magnetic compass is influenced by electrical equipment and metallic objects located near it. These influences cause the compass to deviate from its normal readings. The difference between the indications of a compass in a particular aircraft and the indications of an unaffected compass at the same point on the Earth's surface is called *deviation.* To reduce this deviation, the compensating assembly is adjusted. After the deviation is reduced as much as possible, a deviation card is prepared and mounted near the compass. The figures from this card are applied to the indications of the compass so that the aviator may fly a desired heading.

c. *Magnetic Dip.* The tendency of the magnetic compass to point down as well as north in certain latitudes is known as *magnetic dip.* Magnetic dip is responsible for the northerly and southerly turning error and for the acceleration and deceleration error on headings of east and west. At the magnetic equator, the vertical component of the Earth's magnetic field is zero and the magnetic compass is not disturbed by this factor. While flying from the magnetic equator to higher latitudes, the effect of the vertical component of the Earth's magnetic field becomes pronounced. (Only errors in the Northern Hemisphere are discussed below; the exact reverse of these errors occurs in the Southern Hemisphere.)

(1) *Northerly turning error.* Vertical dip tendency is not noticed in straight-and-level unaccelerated flight. The compass card is mounted so that its center of gravity (CG) is below the pivot point and the card is well balanced in the fluid. When the aircraft is banked, however, the compass card also banks as a result of the centrifugal force acting upon it. While the compass card is in this banked attitude, the vertical component of the Earth's magnetic field causes the northseeking ends of the compass to dip to the low side of the turn, giving an erroneous turn indication (fig 2-4). This error is most apparent on headings of north and south. When making a turn from a heading of north, the compass

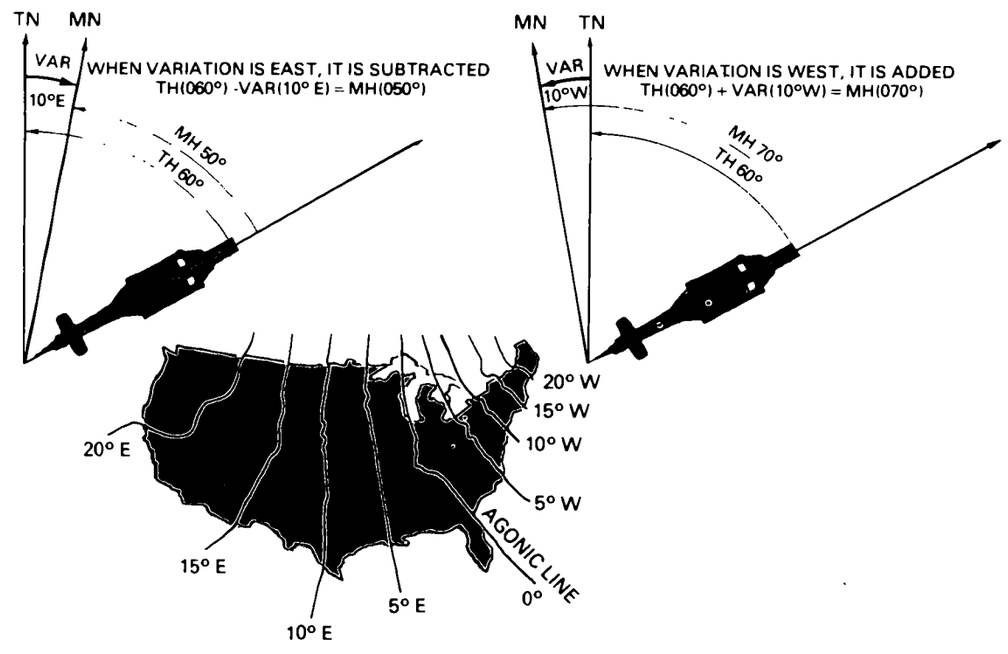
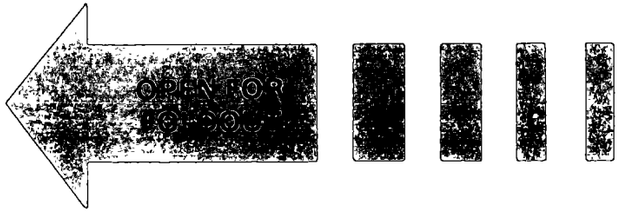


Figure 2-3. Lines of equal magnetic variation in the United States.

the opposite direction and lags behind. When making a turn from a heading of south, it gives an indication of a turn in the proper direction, but at a more rapid rate than is actually being made.

(2) *Acceleration error.* Acceleration error is due to the action of the vertical component of the Earth's magnetic field. The pendulous-type mounting of the compass causes the compass card to tilt during changes in acceleration and pitch. This momentary card deflection from the horizontal results in an error which is most apparent on headings of east and west. When accelerating or establishing a descent on either of these headings, the error is an indication of a turn to the north. When decelerating or establishing a climb, the error is an indication of a turn to the south. If the aircraft is on a north or south heading, no acceleration error is apparent



FM 1-5

while climbing, descending, or changing speed.

(3) *Oscillation error.* Rough air or poor control technique causes erratic swing of the compass card and results in compass oscillation error. The fluid in which the magnetic compass is immersed (para 2-4) is subject to swirl, and this may create noticeable error. Also, the comparatively small size of the compass bowl restricts the use of efficient dampening vanes.

(4) *Errors resulting from the Earth's magnetic field.* The Earth's magnetic lines of flux must be strong enough to cause a bar magnet (as in a compass) to aline with them. The magnetic compass is mounted so that when an aircraft is in straight-and-level unaccelerated flight, the vertical component of the Earth's magnetic field has no effect on the compass indications. In the extreme latitudes (near the North and South Poles), the horizontal component of the Earth's magnetic field is very weak and the compass may spin erratically or indicate improper headings.

(5) *Constructional compensation.* All magnetic compasses are constructed to compensate for disturbing magnetic influences within the aircraft. The compensating mechanism is satisfactory when used with a deviation card ("b" above), as long as the deviation on any particular heading is constant. In modern aircraft, however, the deviation is seldom constant, so the use of the deviation card is limited. In the slaved gyro compass system (para 2-22 through 2-24), the remote compass transmitter is usually located in a wingtip or vertical stabilizer away from aircraft electrical and other magnetic disturbances.

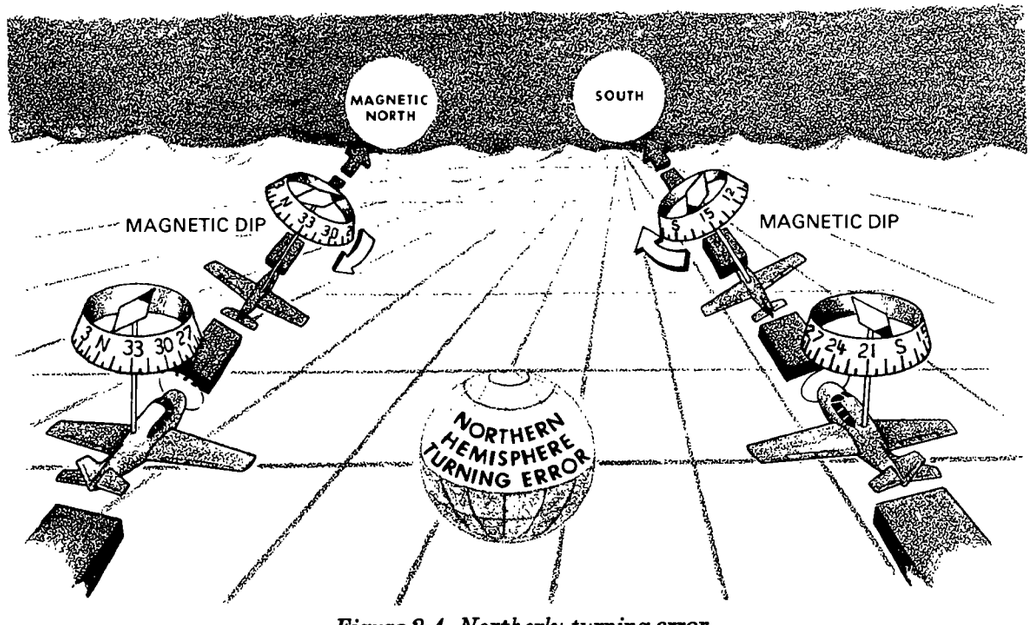


Figure 2-4. Northerly turning error.

Section II. GYROSCOPIC PRINCIPLES

2-4. GYROSCOPE

A gyroscope (fig 2-5) is a wheel or rotor that is mounted to spin rapidly around an axis. It is also free to rotate about one or both of the two axes that are perpendicular to each other and to the axis of spin. A spinning gyroscope offers resistance (inertia) to any force which tends to change the direction of the axis of spin. The rotor (fig 2-5) has great weight (high density) for its size and is rotated at high speeds; therefore, it offers a very high resistance (inertia) to any applied force.

2-5. [illegible]

a. *Free.* A freely (universally) mounted gyroscope has three planes of freedom and is free to rotate in any direction about its center of gravity. The rotor is free to rotate in any plane in relation to the base. The rotor spins so rapidly that its spin axis tends to remain in a fixed direction in space. The freely mounted gyroscope uses the gyroscopic property of rigidity in space. The flight instruments that use this type of mounting are the heading indicator and the attitude indicator.

b. *Semirigid.* A semirigidly mounted gyroscope is mounted so that one of the planes of freedom is held fixed in relation to the base. It uses the gyroscopic properties of rigidity in space and precession (para 2-8). The turn-and-slip indicator, a flight instrument, has a gyroscope which is semirigidly mounted.

2-6. [illegible] OF ACTION

a. *Rigidity in Space.* When spinning, the rotor remains in its original plane of rotation regardless of how the base is moved.

b. *Precession.* This is the resultant action or deflection of a spinning rotor when a deflective force is applied to its rim. Precession is classified as real and apparent.

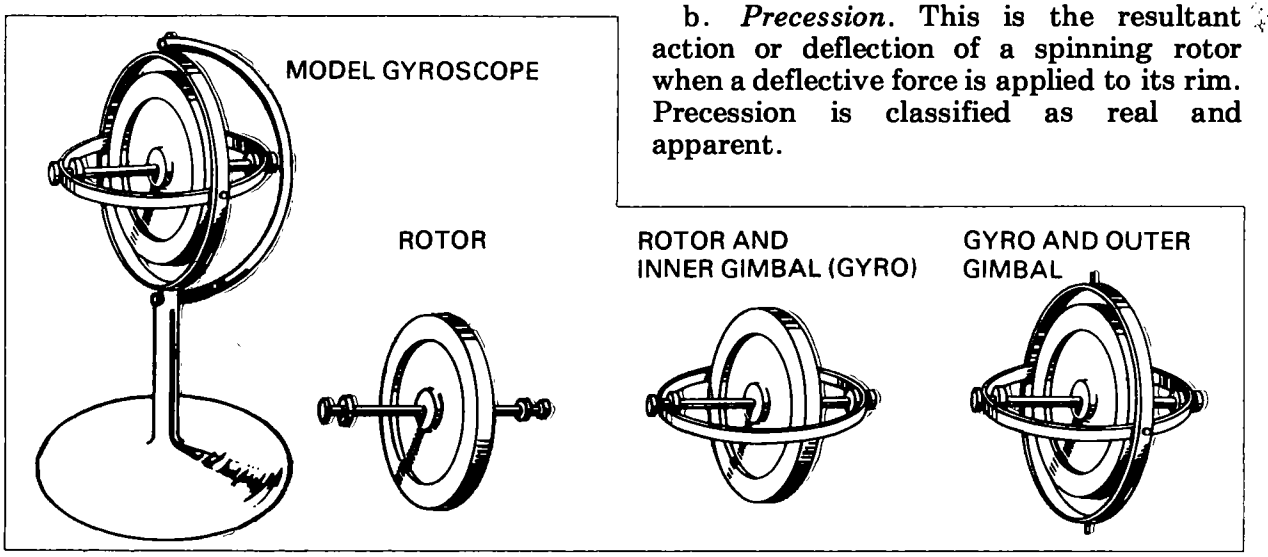


Figure 2-5. Primary elements of a standard gyroscope.

(1) *Real precession.* This is a positive deflection caused directly or indirectly by an applied force or forces. Because of imperfect construction (imperfect balance of the rotor, bearing friction, and friction in the mountings), any gyroscope has some real precession. Other causes of real precession are centrifugal force, gravity force, acceleration, and deceleration.

(2) *Apparent precession.* A freely mounted gyroscope maintains its axis fixed in relation to space and not in relation to the surface of the Earth. As the Earth rotates, carrying the gyro mount around with it, the gyro spin axis maintains its direction in space. With respect to the Earth, the spin axis does change direction. This change in direction is called *apparent precession.*

Section III. GYROSCOPIC INSTRUMENT POWER SOURCES

2-9 GENERAL

Aircraft use either vacuum or electrical power to keep the rotors of gyroscopic instruments rotating continuously. Vacuum operated gyroscopes are reliable to 30,000 feet altitude and at temperatures down to -35° Fahrenheit (F). At higher altitudes and lower temperatures, electrically operated gyroscopes are more reliable.

2-10. VACUUM DRIVEN GYROSCOPE

An engine driven vacuum pump reduces the pressure within the case of a gyroscopic instrument and outside air is then allowed to enter the case through a filter and nozzle. The nozzle directs a stream of air onto the buckets recessed in the rim of the rotor and causes the rotor to turn. The speed of the rotor may vary from 10,000 to 18,000 rpm, depending upon the design of the instrument. Some multiengine aircraft have vacuum pumps on more than one engine so that, if either pump or engine fails, vacuum will not be interrupted. Most modern single engine aircraft do not have an alternate source of vacuum. However, if an engine fails and the propeller continues to windmill, use of proper gliding speed will provide adequate vacuum for instrument operation. A vacuum gage is located on the instrument panel to indicate the suction (vacuum) in inches of mercury (Hg). A suction from 3.75 inches Hg to 4.25 inches Hg will operate the vacuum driven attitude indicator and the directional gyro. A suction from 1.8 inches Hg to 2.1 inches Hg will operate the vacuum driven turn indicator. If the vacuum reading should fall as low as 1.8 inches Hg during flight, the aviator knows that the attitude indicator and heading indicator are unreliable, but the turn indicator is reliable.

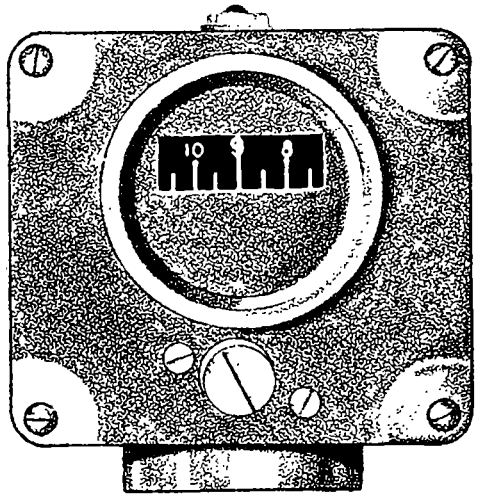
2-11. ELECTRICALLY DRIVEN GYROSCOPES

In electrically driven gyroscopes, the rotor and stator of an electric motor are inclosed in a gyro housing and become, in effect, the gyro. The gyro or rotor is operated on current supplied from the aircraft's electrical system. An advantage of this system is that the case of the instrument can be hermetically sealed. This eliminates the danger of moisture condensation and keeps out foreign material. When the gyro reaches operating speed, enough heat is generated to insure effective lubrication at altitudes where the outside air temperature is extremely low.

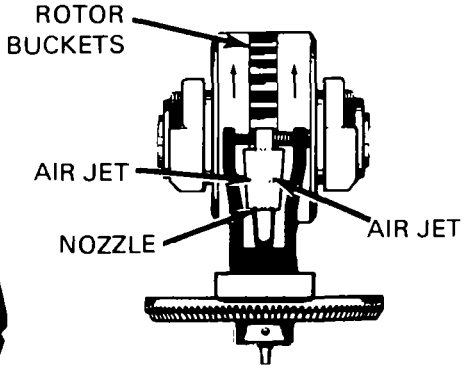
Section IV. GYRO HEADING INDICATOR

2-12. GENERAL

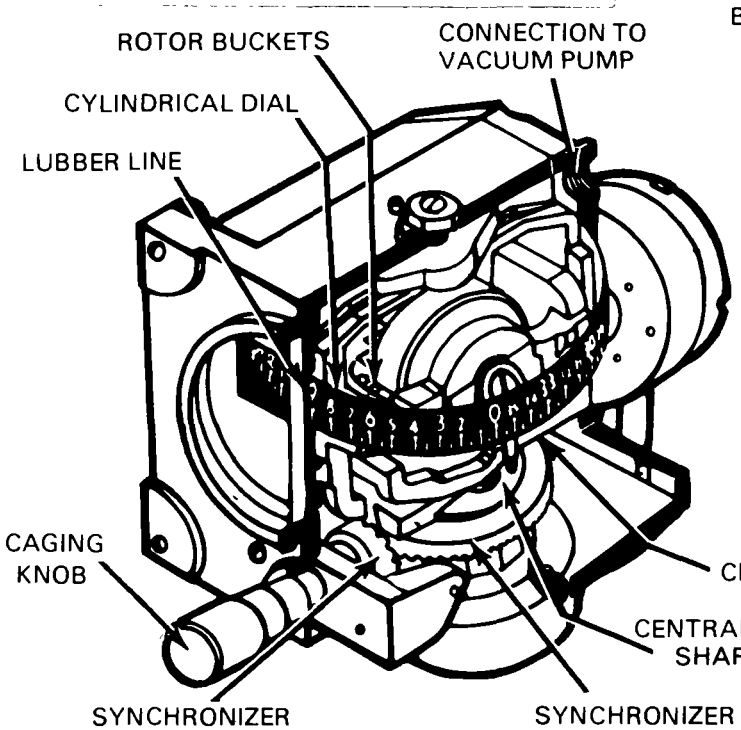
The gyro heading indicator (fig 2-6) is used by the aviator to fly a constant heading and to make turns to headings. It is stable and does not have the errors of the magnetic compass; however, it is not a direction seeking instrument. It must be set to the heading read from the magnetic compass. During flight, the reading under the lubber line of each instrument must be compared with the other; and, when they differ, the gyro heading indicator must be set to the indication of the magnetic compass.



A Indicator face



B Rotor and nozzle assembly



C Cutaway view

NORMAL LIMITS OF OPERATION - 55° PITCH 55° BANK

Figure 2-6. The vacuum driven gyro heading indicator.

The operation of the gyro heading indicator depends upon the gyroscopic property of rigidity in space. A circular compass card (cylindrical dial) is attached at right angles to the plane of the rotor which turns in the vertical plane. Since the rotor remains rigid in space, the points on the compass card hold in a constant direction—the case (attached to the aircraft) simply revolves around the card during turns. The normal limits of operation of the instrument are 55° of pitch and 55° of bank.

a. *Adjustment.* The heading indicator can be set by pushing in on the caging knob, rotating the compass card to the desired heading, and then completely pulling out the caging knob to release the card.

b. *Spinning Card.* When the operating limits of the heading indicator are reached or exceeded, precessional forces cause the compass card to spin rapidly. The spinning can be stopped by pushing in on the caging knob. When the instrument is once again operating within its limits, it should be adjusted as in "a" above.

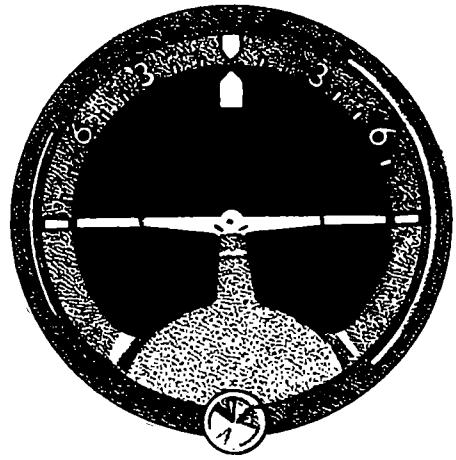
c. *Caging.* During maneuvers which exceed the attitude limits of the instrument, it should be caged by pushing in the caging knob. Exceeding the limits of the instrument, even when caged, causes excessive wear and will shorten the life of the gyroscopic unit.

d. *Precession Errors.* Precession will cause the heading indicator card to lose its position in space and thereby fail to agree with the heading shown on the magnetic compass. This will require an adjustment as in "a" above. If an adjustment of more than 3° in a 15-minute period is required, the precession is considered excessive and this fact should be entered on DA Form 2408-13, "Aircraft Inspection and Maintenance Record."

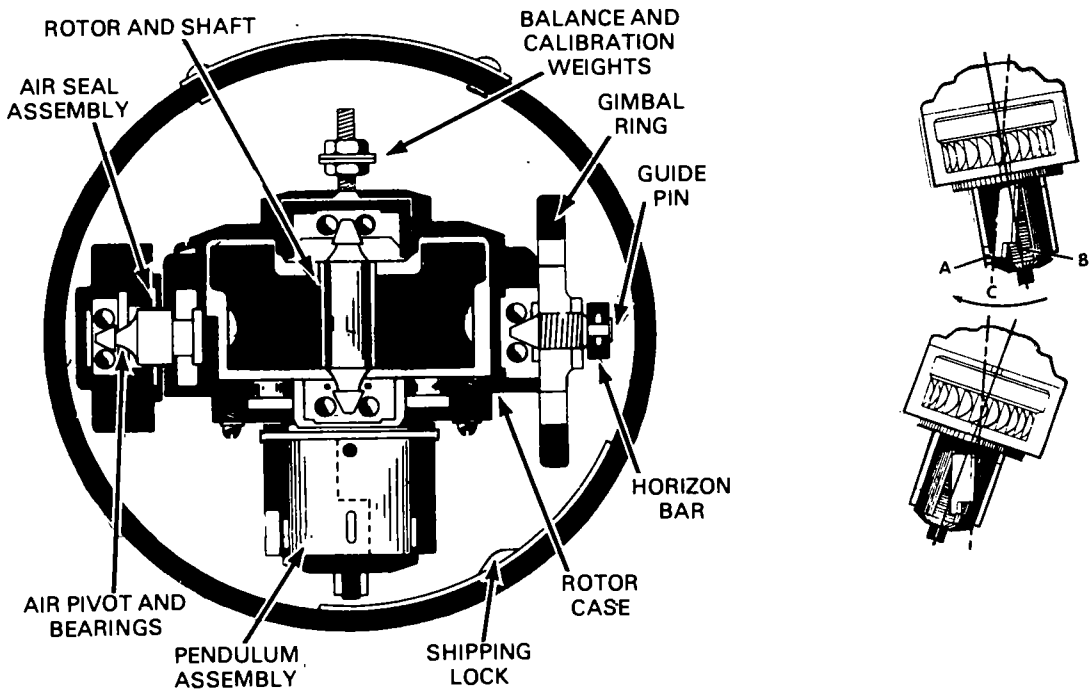
Section V. ATTITUDE INDICATORS

The attitude indicator, with its miniature aircraft (representing the actual aircraft) and the horizon bar (representing the actual horizon outside the aircraft), is the only flight instrument that directly displays the flight attitude of the aircraft. It simultaneously displays both the pitch and bank attitudes of the aircraft. It has no lead or lag in response to changes in the aircraft attitude and provides instantaneous indications of even the smallest change in attitude.

Attitude indicators are powered either by a vacuum (suction) or an electrical source. The vacuum driven attitude indicator (fig 2-7), along with other vacuum driven instruments in the aircraft, is attached to the vacuum system. This system has a gage, in view of the aviator, which indicates whether or not there is sufficient suction for reliable operation of the instruments. The electrically operated attitude indicator (fig 2-8, 2-9, and 2-10) has a warning flag which appears on the face of the instrument whenever the electrical source is interrupted.

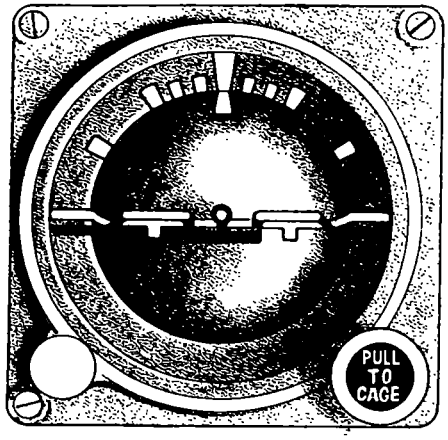


A Indicator face

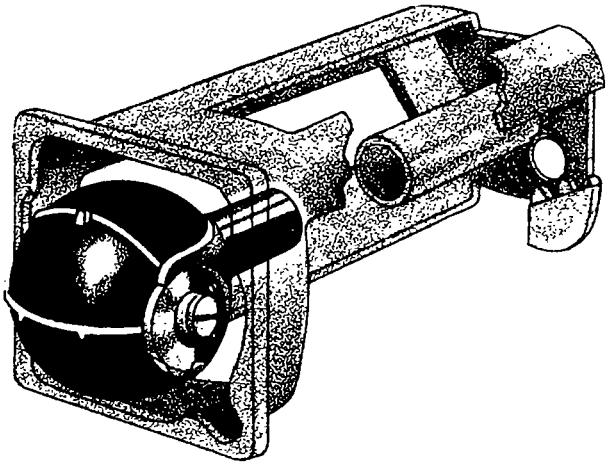


B Rotor assembly

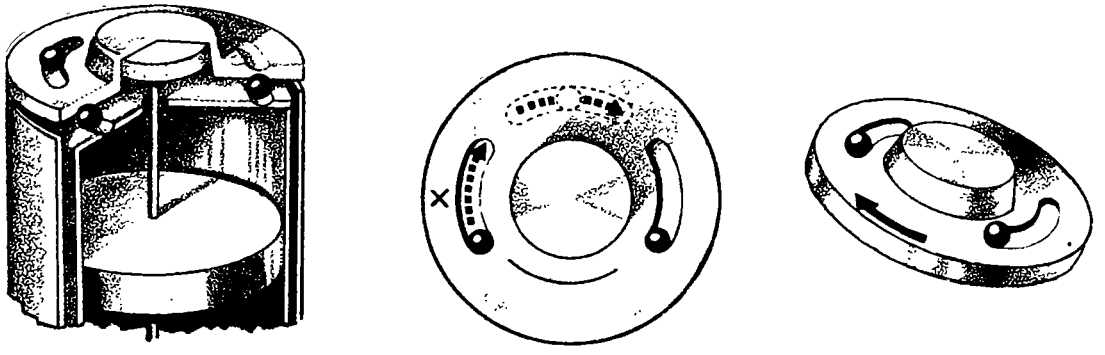
Figure 2-7. The vacuum driven (suction) attitude indicator.



A. Indicator face



B. Gyro housing and component parts



C. Erection mechanism

Figure 2-8. The J-8 electric attitude indicator.

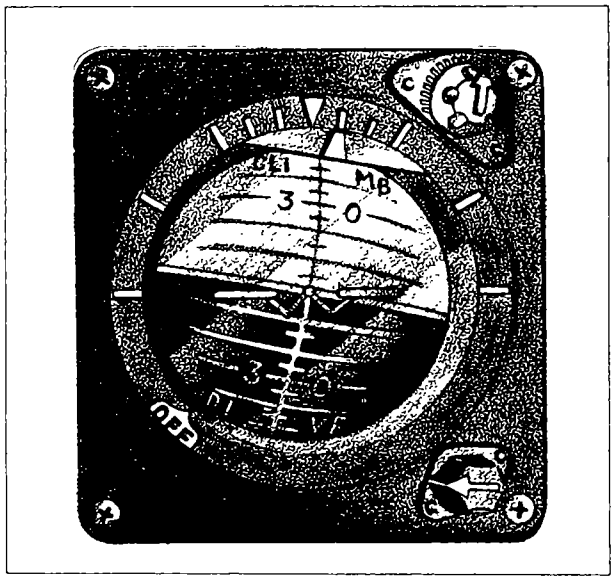


Figure 2-9. The Lear model electric attitude indicator 4005G.

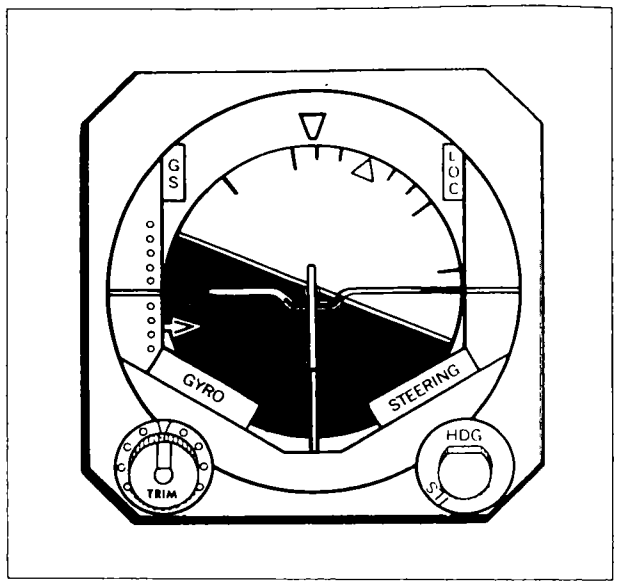


Figure 2-10. Navigation electric attitude indicator ID-882.

2-16. CONSTRUCTION

Attitude indicators have a device to represent the natural horizon. This may be a horizon bar, a horizon line, or a sphere or disk with a line separating a light color which represents the sky from a dark color which represents the Earth. A banking pointer is positioned at the top of the instrument face to indicate the banking attitude of the aircraft. A device representing a miniature aircraft is mounted in front of the horizon bar, sphere or disk. On some attitude indicators this device can be adjusted up or down by a knob located on the instrument case. This is done in order to place the miniature aircraft in the desired position in relation to the horizon bar or horizon line. Other attitude indicators have a knob which is used to adjust the horizon line in order to place it in the desired position in relation to the miniature aircraft. The horizon bar, sphere or disk, and the banking pointer are held rigid in space by a gyroscope so that the horizon line or horizon bar remains parallel to the natural horizon and the banking pointer remains perpendicular to the natural horizon. This establishes a level reference plane inside the aircraft. The case of the instrument, which is attached to the aircraft, moves with the aircraft as it changes its attitude. In this way the attitude of the aircraft is displayed on the attitude indicator in both pitch and bank.

2-17. OPERATION

a. The rotor housing of the vacuum operated attitude indicator will contact stops on the inside of the instrument case whenever the bank attitude of the aircraft is greater than 110° or the pitch attitude is greater than 70°. These stops prevent 360°

rotation of the case around the rotor housing. The instrument "tumbles" when the rotor housing hits the stops. Tumbling is recognized by rapid displacement of the horizon bar and banking pointer. The instrument is then unusable for controlling the attitude of the aircraft. However, as soon as the aircraft becomes less than the above limits in pitch and bank, the erecting mechanism within the instrument will place the rotor housing back to its normal position. This may take several minutes depending on the operating efficiency of the instrument. A more rapid replacement of the rotor housing to its normal position may be accomplished by pulling out the caging knob located on the front of the instrument case. As soon as the horizon bar and banking pointer stop in the caged position, the caging knob should be released. To determine whether or not the caging mechanism has completely released, push the caging knob against the instrument case.

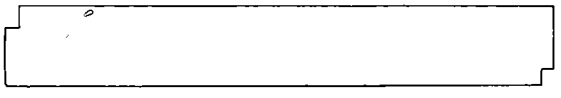
b. The electric attitude indicators have gyroscopes which are mounted so as to allow 360° movement of the instrument case in both pitch and bank. If the instrument has a caging knob, it may be used to quickly erect the gyroscope after power has been applied to it or to erect it when in-flight errors have been induced in the instrument.

c. Caging of an attitude indicator should be done only when the aircraft is in level flight. If uncaged in an unlevel flight attitude, it will remain in an unlevel attitude until the erecting mechanism has placed it back in its usual operating position.

d. Attitude indicators may have small errors in operation due to precession. This may be caused by uncoordinated use of the aircraft controls in flight, by turning of the aircraft, by acceleration or deceleration of the aircraft in flight, and by poor mechanical condition of the instrument. Many of these errors will be so small and of such short duration that the aviator will not be aware of them. The errors will usually be detected by reference to the other flight instruments. If the instrument is in good operating condition, the erecting mechanism will complete its correction of the error in a reasonable time after the error-inducing condition is no longer present.

For operation of the attitude indicator in each aircraft, the aviator must consult the operator's manual.

Section VI. TURN-AND-SLIP INDICATOR



The turn-and-slip indicator (fig 2-11) is a combination of two instruments—a turn needle and a ball. The turn needle depends on gyroscopic precession for its indications and the ball is actuated by gravity and centrifugal forces. Although some vacuum operated turn needles are still in use, the majority are electrically operated. In either case, the gyroscopic properties used are the same. The gyro has a horizontal spin axis with a restricted mounting and is only free to tilt. The tilting of the gyro is displayed to the pilot as a deflection of the turn needle.

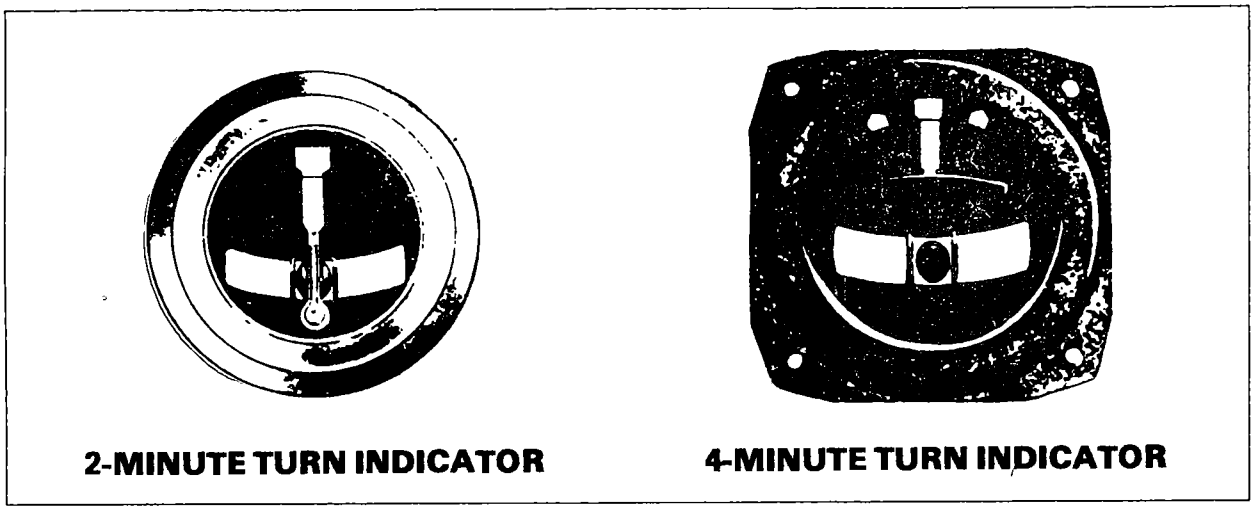


Figure 2-11. Turn-and-slip indicator.

2-20. THE TURN NEEDLE

The deflection of the turn needle away from its vertical or centered position indicates that the aircraft is turning in the direction of the deflection, and the amount of deflection from the centered position is proportional to the rate of turn in degrees per second. The rate of turn depends on whether the instrument is a 2-minute or 4-minute turn needle. A 360° turn with a single-needle width deflection will require 2 minutes with a 2-minute turn needle (fig 2-11) and 4 minutes with a 4-minute (fig 2-11) turn needle. The rate of turn with a single-needle width deflection is 3° per second with a 2-minute turn needle and 1 1/2° per second with a 4-minute turn needle. A rate of turn of 3° per second on a 4-minute turn needle will require a two-needle-width deflection of the turn needle.

2-21. THE BALL

The ball part of the turn-and-slip indicator consists of a sealed, curved glass tube containing kerosene and a black agate or steel ball bearing which is free to move inside the tube. The fluid provides a dampening action and insures smooth and easy movement of the ball. The tube is curved so that the ball seeks the lowest point at its center. A small projection of the left end of the tube contains a bubble of air which compensates for expansion of the fluid during changes in temperature. Two strands of safety wire are wound around the glass tube as reference markers to indicate the correct position of the ball in the tube. The forces acting on the ball are gravity and centifugal force.

a. *In Straight Flight.* During straight flight, the force of gravity causes the ball to rest in the lowest part of the tube between the reference markers.

b. *In a Balanced Turn.* In a balanced (or coordinated) turn, gravity and centrifugal forces are in balance and the ball remains between the reference markers.

c. *In an Unbalanced Turn.* When the forces acting on the ball become unbalanced or unequal, the ball moves away from its position between the reference markers. The following unbalanced conditions are:

(1) *A skid.* In a skid the rate of turn is too great for the angle of bank. The centrifugal force is greater than gravity and the ball moves out of its centered position and toward the outside of the turn. Correcting to a balanced flight requires an increase of the angle of bank, a decrease in the rate of turn, or an adjustment of both until the forces are in balance.

(2) *A slip.* In a slip,the rate of turn is too slow for the angle of bank. Gravity is greater than centrifugal force and the ball moves from its centered position and toward the inside of the turn. Correcting to a balanced flight requires a decrease of the angle of bank, an increase in the rate of turn, or an adjustment of both until the forces are in balance.

d. *As a Balance Indicator.* The ball instrument aids in achieving correct coordination. Correct coordination in fixed wing aircraft is achieved by proper use of the ailerons and rudder in relation to each other. It is achieved in rotary wing aircraft by proper use of the antitorque pedals and the cyclic in relation to each other. The ball instrument also aids in correctly setting the aileron and rudder trim in fixed wing aircraft during flight.

Section VII. SLAVED GYRO COMPASS SYSTEMS

2-22. GENERAL

The slaved gyro compass (fig 2-12) is a gyro-stabilized magnetic compass. The slaved gyro compass system may be operated as a magnetically slaved gyro compass over areas of the Earth's surface, where the Earth's magnetic field of force is usable. Each system may also be operated as a free gyro heading indicator in areas where the Earth's magnetic field is unusable ("b" below).

a. *Slaved Gyro Mode of Operation.* In the slaved mode of operation, a direction-sensing device called a *flux valve* detects the angular position of the Earth's magnetic field with respect to the aircraft. This information is fed to a drive unit used to aline the gyro. From the gyro a stabilized heading indication is presented to the aviator.

b. *Free Gyro Mode of Operation.* In the free mode of operation, the direction-sensing flux valve is disconnected from the system, and the gyro is used only as a heading reference indicator. The aviator must originally set the heading indicator to correspond to the aircraft heading. The aircraft heading can be obtained from a standby magnetic compass or by alinement with the runway, etc. Since the gyro is not slaved to the flux valve unit, the heading indicator is subject to drift. The aviator should periodically check the heading indications with those of his standby source of heading reference and reset if necessary.

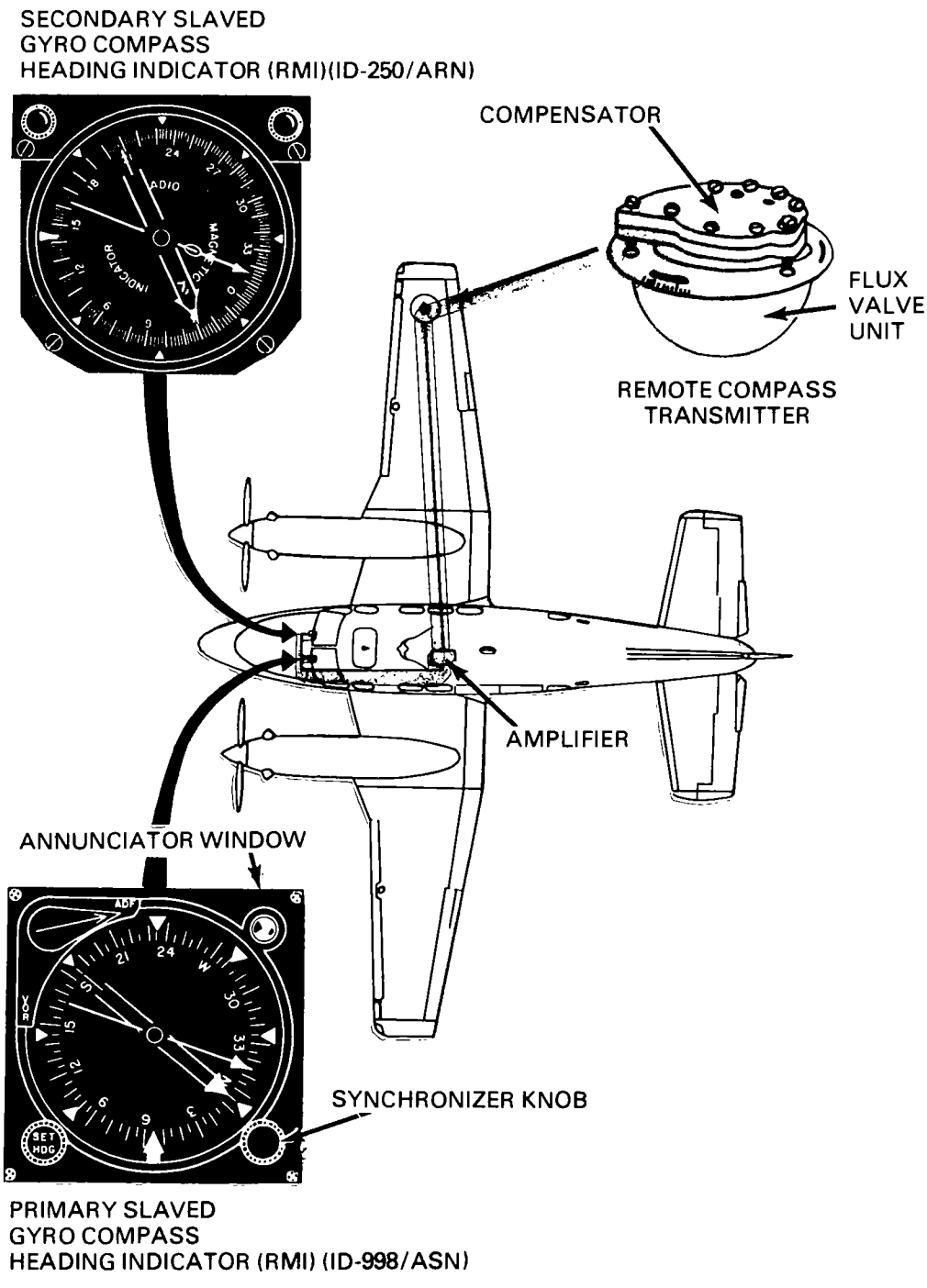


Figure 2-12. Components of a typical slaved gyro compass system.

Essentially, each slaved gyro compass system consists of a compass transmitter, an amplifier, a directional gyro, a primary heading indicator, and normally, a repeater heading indicator.

a. *Compass Transmitter.* The compass transmitter contains the flux valve unit, which is the direction-sensing device of the system. This unit detects the horizontal components (or lines of flux) of the Earth's magnetic field and is suspended by a universal joint. The unit is weighted so that it normally maintains a horizontal plane. The universal suspension allows the flux valve to hang like a plumb bob and swing in a pendulous manner. The flux valve unit cannot rotate and is fixed to turn with the aircraft. Any change in direction by the aircraft results in a corresponding change of the flux valve unit in relation to the Earth's magnetic field. This field of force induces an electrical voltage in the flux valve unit which is transmitted through the amplifier to the directional gyro control. Since the heading information is transmitted electrically to the gyro, the unit can be installed at a remote part of the aircraft (e.g., wingtip) where magnetic deviation is at a minimum. A mechanical compensator further reduces the deviation effect.

b. *Amplifier.* The amplifier is the coordinating and distributing center of the slaved gyro compass system. Its principal function is to increase the strength of the signals from the compass transmitter. Normally, the amplifier also serves as the power supply and junction box of the compass system.

c. *Directional Gyro.* The directional gyro maintains a constant directional reference by using the gyroscopic property of rigidity in space (para 2-8a). The case of the directional gyro control unit rotates in azimuth about the directionally stabilized gyro as the aircraft turns. As the aircraft rotates about the gyro, the turn information is relayed to the primary heading indicator and the repeater indicator. The directional gyro maintains its reference to magnetic north by signals received from the remote compass transmitter. These signals operate a torque motor in the directional gyro control. The torque motor precesses the gyro unit until it is alined with the transmitter signal, thus slaving the gyro to the Earth's magnetic meridian. The gyro is free to operate within 85° from the level flight attitude, both in pitch and bank. When these limits are exceeded, the gyro strikes mechanical stops. This causes erroneous indications to appear on the heading indicators until the directional gyro is again slaved through the compass transmitter to the magnetic meridian. Induced errors may be as large as 5°; however, the gyro will erect fully in 5 minutes or less.

d. *Heading Indicators.* The heading indicators (fig 2-13 and 2-14) in gyro compass systems may be either *primary* or *repeater.*

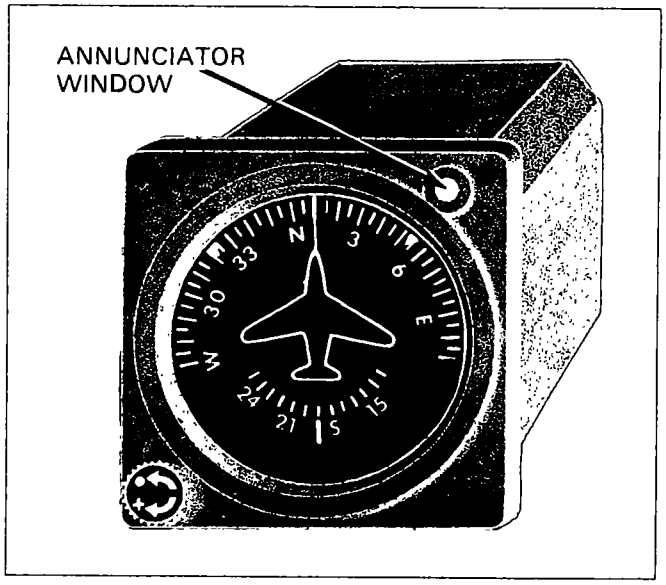


Figure 2-13. Heading indicator ID-567/ASN.

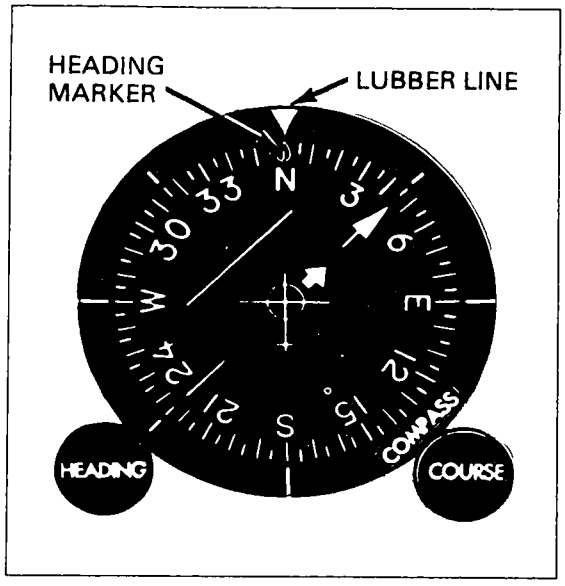


Figure 2-14. Course indicator ID-883.

(1) *Primary.* Some primary heading indicators have an annunciator window and a gyro synchronizing control knob. The annunciator window shows the direction in which the synchronizing knob should be rotated. If the gyro controls are not found on the primary heading indicator, they will be found on the gyro control panel.

(2) *Repeater.* The repeater dial may look exactly like the primary dial, but it merely repeats the indications on the primary indicator. The repeater indicator does not have a synchronizing knob.

2-24. OPERATION OF SLAVED GYRO COMPASS SYSTEM

For operation of the slaved gyro compass system in each aircraft, the aviator must consult the operator's manual.

Section VIII. THE PITOT-STATIC SYSTEM

2-25. GENERAL

The pitot-static system (fig 2-15) is the source of power for the operation of the differential pressure instruments—the altimeter, vertical speed indicator, instantaneous vertical speed indicator (IVSI), and the airspeed indicator. The differential pressure used to power these instruments is created either by impact and static or by static and trapped air pressures. The pitot-static system supplies both impact and static pressures through connecting lines to the instruments. The indications on the calibrated scales of these instruments result from differences in air pressure that exist within each of the instruments. To

interpret the indications of these instruments properly, it is essential for the aviator to understand the construction, operation, and use of the entire pitot-static system.

2-26. IMPACT PRESSURE

Impact pressure is required for the operation of the airspeed indicator. The open pitot tube is mounted on the aircraft, parallel to the longitudinal axis of the aircraft, where there is a minimum disturbance of air caused by aircraft motion. Two major parts make up the pitot tube—the impact pressure chamber with lines and the heating unit. The pitot tube receives the impact pressure of the air. This impact pressure increases with the speed of the aircraft. Since the diaphragm (fig 2-24) of the airspeed indicator is connected directly to the pitot line, it is expanded by this increase in impact pressure. The expansion or contraction of the diaphragm, in turn, controls the position of the airspeed needle by a series of levers and gears. During preflight inspection, the aviator must remove any cover that is over the impact opening of the pitot tube.

[redacted]PRESSURE

To obtain the required difference in pressure for the operation of the differential pressure instruments, static air pressure from the atmosphere is supplied to the instruments through static vents (or static ports) (fig 2-15). To minimize sensing errors, the static vents are located in an area that has the least disturbed airflow. Some aircraft have these vents located on the pitot tube; however, the majority of subsonic aircraft have them located on both sides of the fuselage. These vents are connected to a common line by a Y-fitting. By placing and connecting the vents in this manner, there is a minimum error in static pressure due to erratic changes in the attitude of the aircraft during flight. During preflight inspection, the aviator must check these vents to see that they are

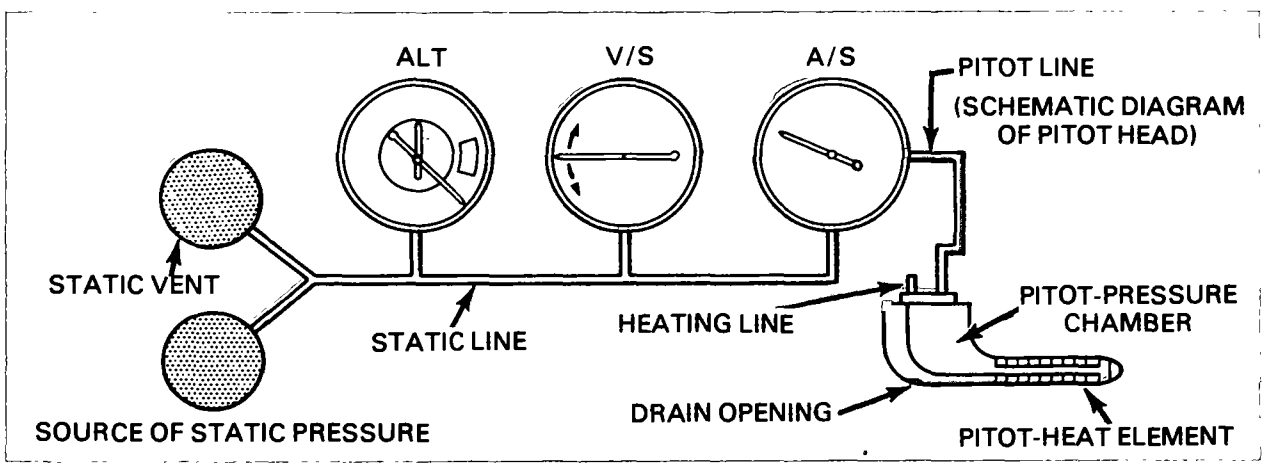


Figure 2-15. Flush type pitot-static system.

unobstructed. Also, check that nothing has damaged or changed the size of one or more of these vents. Distorting the holes or the surrounding skin area a few thousandths of an inch can cause pressure sensing errors.

a. *Alternate Source of Static Pressure.* An alternate source of static pressure is provided in some aircraft in the event the normal system becomes obstructed by ice or otherwise fails. The alternate static vent (or vents) is usually located at a point in the airframe that is not susceptible to icing conditions. When this alternate source is located within the cockpit or cabin, there is usually a difference between the static pressure it supplies and that supplied by the normal system. Also, the opening of storm windows, air vents, or the operation of the heating/ventilating system may introduce a further change in the pressure supplied by the alternate source. When the aviator switches to the alternate source, the indications of airspeed and altitude will usually change and the vertical speed indicator will momentarily indicate a climb or descent. The amount and direction of the instrument errors are normally available from charts in the pilot's handbook for the aircraft. The corrections indicated by these charts should be applied to the airspeed indicator and altimeter during flight.

b. *Emergency Alternate Source of Static Pressure.* If the normal static system is inoperative and the aircraft has no alternate source, static pressure may be obtained by breaking the glass on any one of the differential pressure instuments. It is difficult to break the glass without damaging the instrument. For this reason, it is advisable to break the glass on the vertical speed indicator since this is the least important of the differential pressure instruments. If the glass of the vertical speed indicator is broken and the instrument is still operating, its indications will be the reverse of normal indications. The altimeter and airspeed indicator will lag in their indications because the static pressure now comes from inside the cockpit and forces its way to the instruments through the calibrated leak in the vertical speed indicator.

Section IX. THE PRESSURE ALTIMETER

The atmosphere surrounding the Earth exerts downward pressure because of its weight. The air near the Earth is weighted down and compressed by the air above and thus has greater density than the air above. This difference in pressure at various levels is used by the altimeter. The *pressure altimeter* (fig 2-16) is essentially a pressure measuring device calibrated to convert atmospheric pressure to an altitude indication. The conversion is based on a fixed set of values known as the US Standard of Atmosphere. A portion of these values is tabulated in table 2-1. Although these atmospheric values exist only on paper, they were constructed by a formula which approximates the average pressure and temperature of 45° north latitude in the United States. Up to an altitude of about 15,000 feet, pressure decreases approximately 1 inch Hg per 1,000 feet. A pressure setting knob (fig 2-16) compensates for nonstandard conditions of surface pressure that exist from hour to hour (para 2-30b).

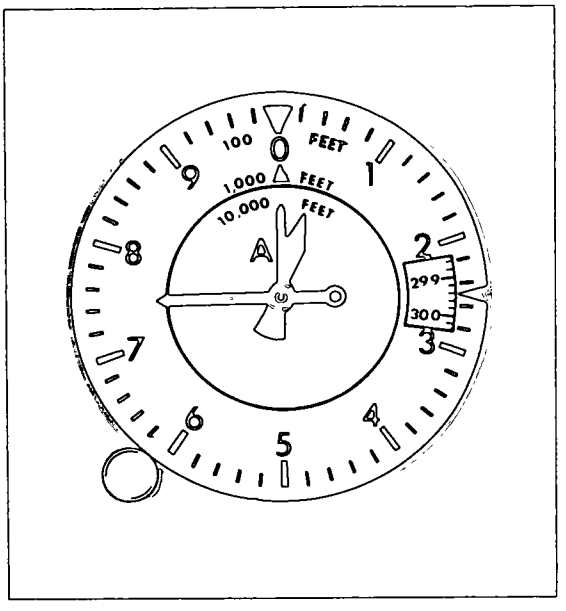


Figure 2-16. The pressure altimeter.

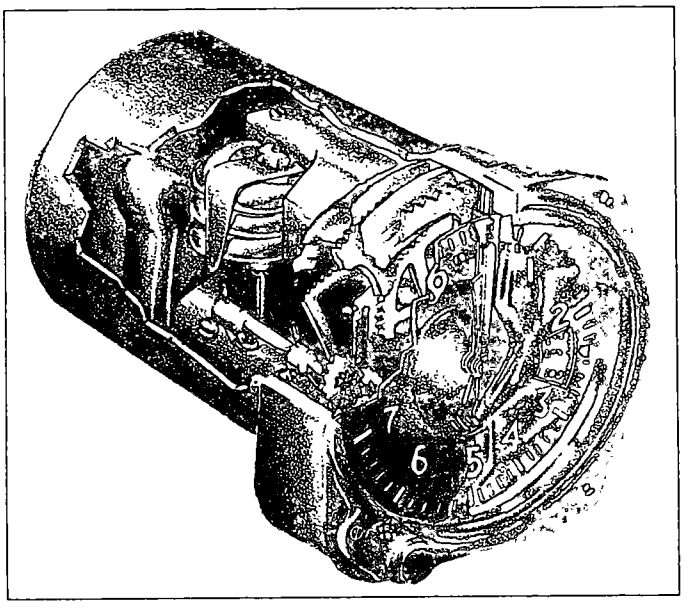


Figure 2-17. Cutaway view of the altimeter.

2-29. CONSTRUCTION OF ALTIMETER

The basic component of the pressure altimeter is a series of aneroid wafers (fig 2-17). The aneroid wafers are airtight cells from which nearly all of the air has been evacuated. This series of interconnected wafers contracts or expands with changes of atmospheric pressure. As the aircraft altitude increases, the static pressure surrounding the wafers decreases and allows the wafers to expand. When the aircraft altitude decreases, the static pressure surrounding the wafers increases, causing the wafers to contract. One end of the stack of the wafers is attached to the instrument case and the other is linked by a lever to a shaft. A linkage and gear assembly is also connected to the shaft. Expansion or contraction of the wafers causes the shaft to rotate. This rotation through the gearing mechanism positions the hands on the altimeter dial to indicate the altitude.

2-30. READING THE ALTIMETER

The altimeter dial (fig 2-16) is properly read by noting the position of all three hands in order, from the shortest to the longest. The shortest hand indicates tens of thousands; the intermediate hand thousands; and the longest hand hundreds. Figure 2-16 illustrates 750 feet.

a. The old type altimeter dial (fig 2-16) has been modified because of difficulty in rapidly determining thousands and tens of thousands of feet. The MB-2 (fig 2-18) was developed both as a new altimeter and as a conversion of older models. It has a

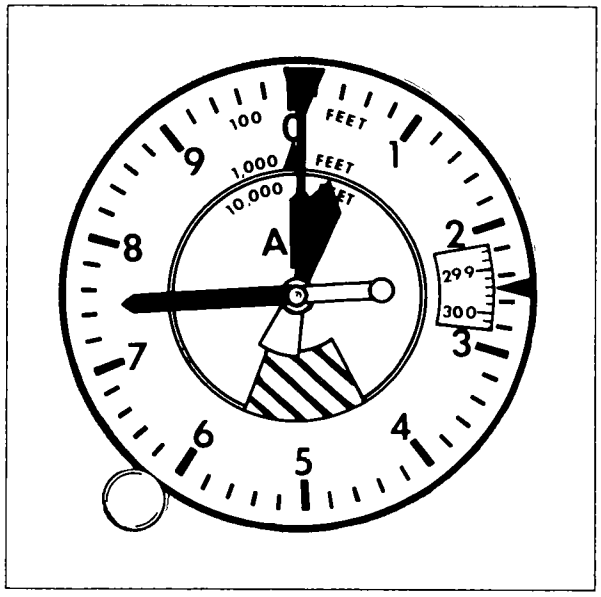


Figure 2-18. The MB-2 altimeter dial.

crosshatched "flag" on the lower part of the dial and, instead of a 10,000-foot needle, it has a disk with a pointer extending out to the edge of the dial. A hole in the disk is located so that the edge of the flag barely shows at about 15,000 feet; at altitudes below 10,000 feet, the whole flag shows.

b. A barometric scale is visible through an opening (Kollsman window) in the right-hand side of the altimeter dial. This scale is calibrated from 28.10 to 31.00 inches Hg, and is rotated by the pressure setting knob. In the type of altimeter illustrated in figure 2-16, the rotation of the pressure setting knob also moves the reference marks. These reference marks provide an alternate means (in hundreds of feet and thousands of feet) of adjusting the altimeter in the event that sea level pressure is outside the range of the barometric scale. Rotating the setting knob provides altimeter adjustment to non-standard conditions of pressure (other than those in table 2-1). For example, assume that an altimeter is placed on the beach and is set at 29.92 inches Hg. If the hands indicate an altitude of 200 feet, the barometric pressure at that point on the beach is lower than standard. A barometric pressure of 29.72 inches Hg will cause a 200-foot-high indication if 29.92 inches Hg is set into the Kollsman window; if 29.72 inches Hg is rotated into the Kollsman window, the hands of the altimeter will return to zero. (One inch Hg equals 1,000 feet; 0.20 inch Hg equals 200 feet.) In effect, the hands have been assigned a different pressure for their zero indication. Rotating the setting knob on the altimeter merely displaces the hands a given amount with respect to the aneroid wafers.

TABLE 2-1. STANDARD PRESSURE AND TEMPERATURES AT 1,000-FOOT INTERVALS

Feet	Pressure (inches Hg)	Degrees temperature (C)
16,000	16.21	-17
15,000	16.88	-15
14,000	17.57	-13
13,000	18.29	-11
12,000	19.03	-9
11,000	19.79	-7
10,000	20.58	-5
9,000	21.38	-3
8,000	22.22	-1
7,000	23.09	1
6,000	23.98	3
5,000	24.98	5
4,000	25.84	7
3,000	26.81	9
2,000	27.82	11
1,000	28.86	13
Sea Level	29.92	15

c. Another type of pressure altimeter is the counter-drum-pointer altimeter. One model of this altimeter is the AIMS altimeter, the AAU-32/A (fig 2-19). In the term AIMS, the A stands for ATCRBS (Air Traffic Control Radar Beacon System), the I stands for IFF (identification, friend or foe (radar)), the M represents the Mark XII identification system, and S is for system. This altimeter is used in aircraft whose systems have a negligible installation error. It is a self-contained unit which consists of a precision aneroid altimeter combined with an encoder. The altitude is displayed to the aviator by the counter-drum-pointer dial and the encoder generates a signal which transmits the altitude to the air traffic control equipment through the aircraft transponder. Two techniques may be used by the aviator to read the altimeter:

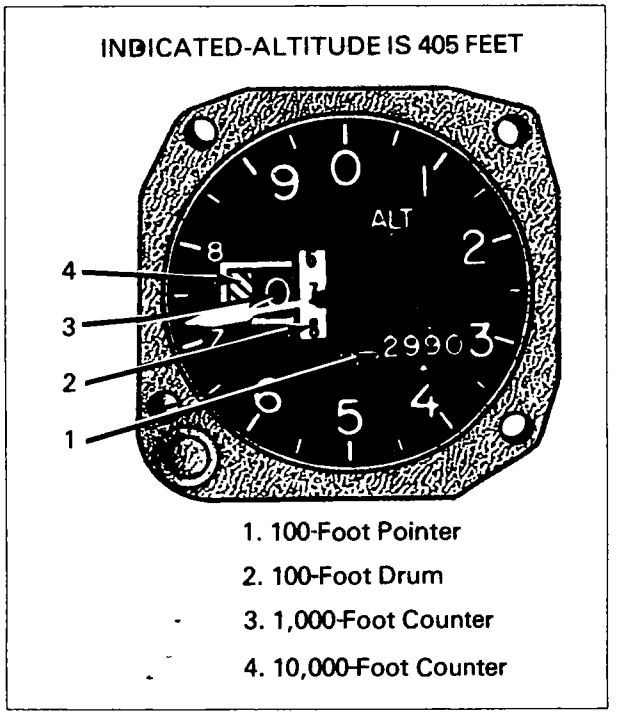


Figure 2-19. Counter-drum-pointer altimeter.

(1) Read the counter-drum window, without referring to the 100-foot pointer, as a direct digital readout of both thousands and hundreds of feet; or

(2) Read the two counter indications, without referring to the drum, and then add the 100-foot pointer indication. The 100-foot pointer serves as a precise readout of values less than 100 feet required for determining lead points for leveloff altitudes, maintaining level flight, and during instrument approaches. If the "code-OFF" flag, located on the upper left of the altimeter face is visible, it means that the alternating current (AC) power is not available, the circuit breakers are not in, or there is an internal altimeter encoder failure. This indicates that the encoder is not operating and that no altitude information is being furnished through the transponder to the air traffic control equipment. However, this does not affect the ability of the instrument to indicate the correct altitude to the aviator.

Atmospheric temperature and pressure vary continuously. Rarely is the pressure at sea level exactly 29.92 inches Hg or the temperature +15° C (centigrade). Furthermore, the temperature and the pressure may not decrease with altitude increasing at a standard rate. Even if the altimeter is properly set for surface conditions, it will often be incorrect at higher levels. On a warm day, the air expands and weighs less per unit volume than on a colder day, and

the pressure levels are raised. On a cold day, the reverse would be true.

a. *Altimeter Error Due to Nonstandard Temperature.* If the air is warmer than the standard temperature for the flight altitude, the aircraft will be higher above sea level than the altimeter indicates; if the air is colder than the standard temperature for the flight altitude, the aircraft will be lower than the altimeter indicates (fig 2-20). The altimeter provides no way for the aviator to adjust it for nonstandard temperatures. However, since instrument flight in controlled airspace is accomplished at assigned indicated altitudes, aircraft separation is maintained because all aircraft using the same altimeter setting and flying in the same general area are equally affected by any nonstandard temperature. In selecting altitudes for flight over mountainous terrain where no minimum obstruction clearance information is available, the aviator must take into consideration nonstandard temperatures aloft (para 2-32b(2)).

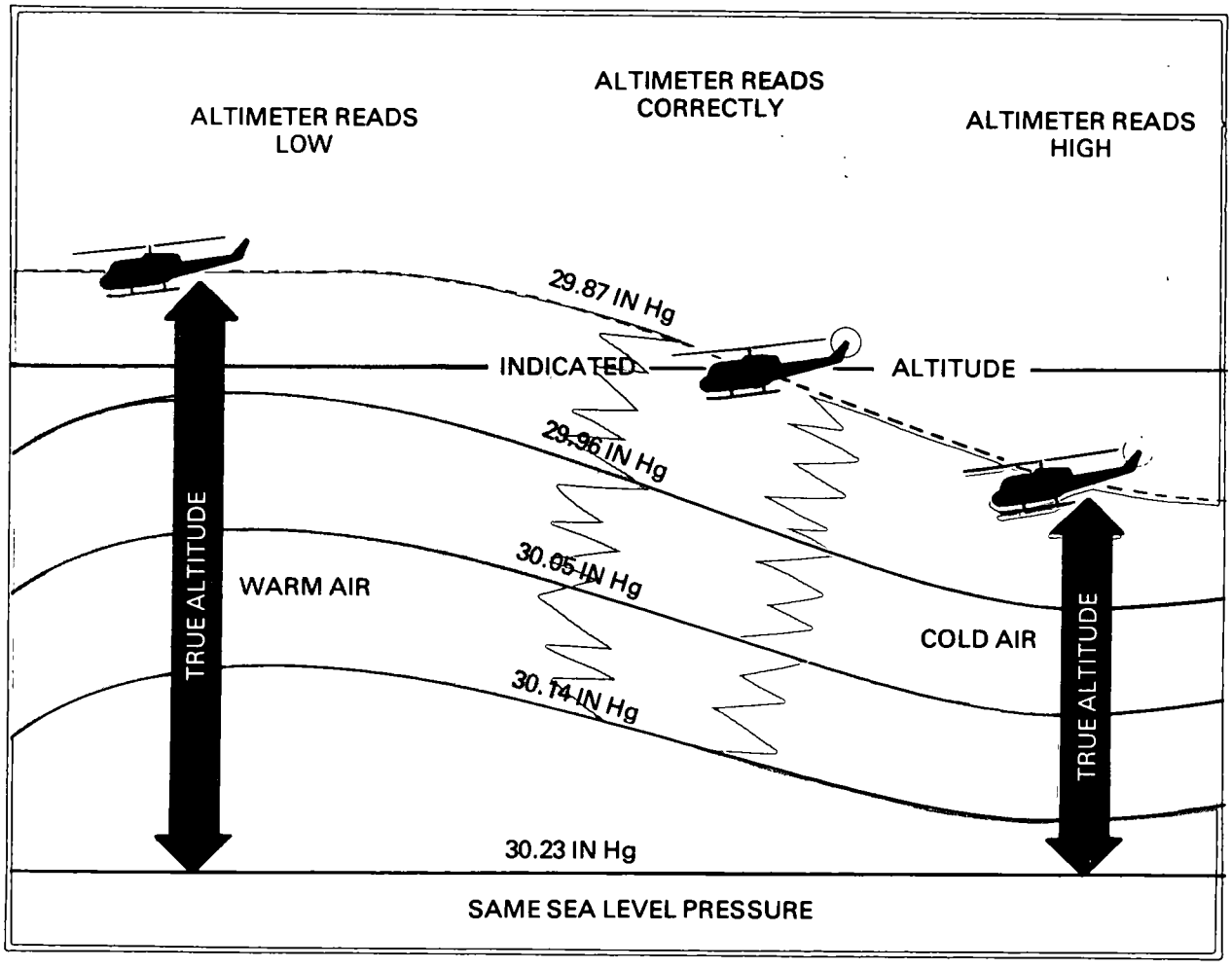


Figure 2-20. Altimeter errors due to nonstandard temperatures.

b. *Altimeter Error Due to Nonstandard Atmospheric Pressure.* Figure 2-21 shows the error in altimeter reading that would result if the aviator failed to adjust the altimeter for variations from standard atmospheric pressure. The figure shows a pattern of isobars in a cross section of the atmosphere from Pensacola, Florida, to New Orleans, Louisiana. The pressure at Pensacola is 30.00 inches Hg and the pressure at New Orleans is 29.60 inches Hg—a difference of 0.40 inch Hg. Assuming that the aircraft takes off from Pensacola to fly to New Orleans at an altitude of 700 feet, a decrease in mean sea level (MSL) pressure of 0.40 inch Hg from Pensacola to New Orleans could cause the aircraft to gradually lose altitude and, although the altimeter would continue to indicate 700 feet, the aircraft could actually be flying at approximately 300 feet over New Orleans.

2-32. SETTING THE ALTIMETER

a. *Current Altimeter Setting.* The current altimeter setting is normally given to the aviator during radio communications with Federal Aviation Administration (FAA) flight service stations (FSS), airport control towers, and other air traffic control

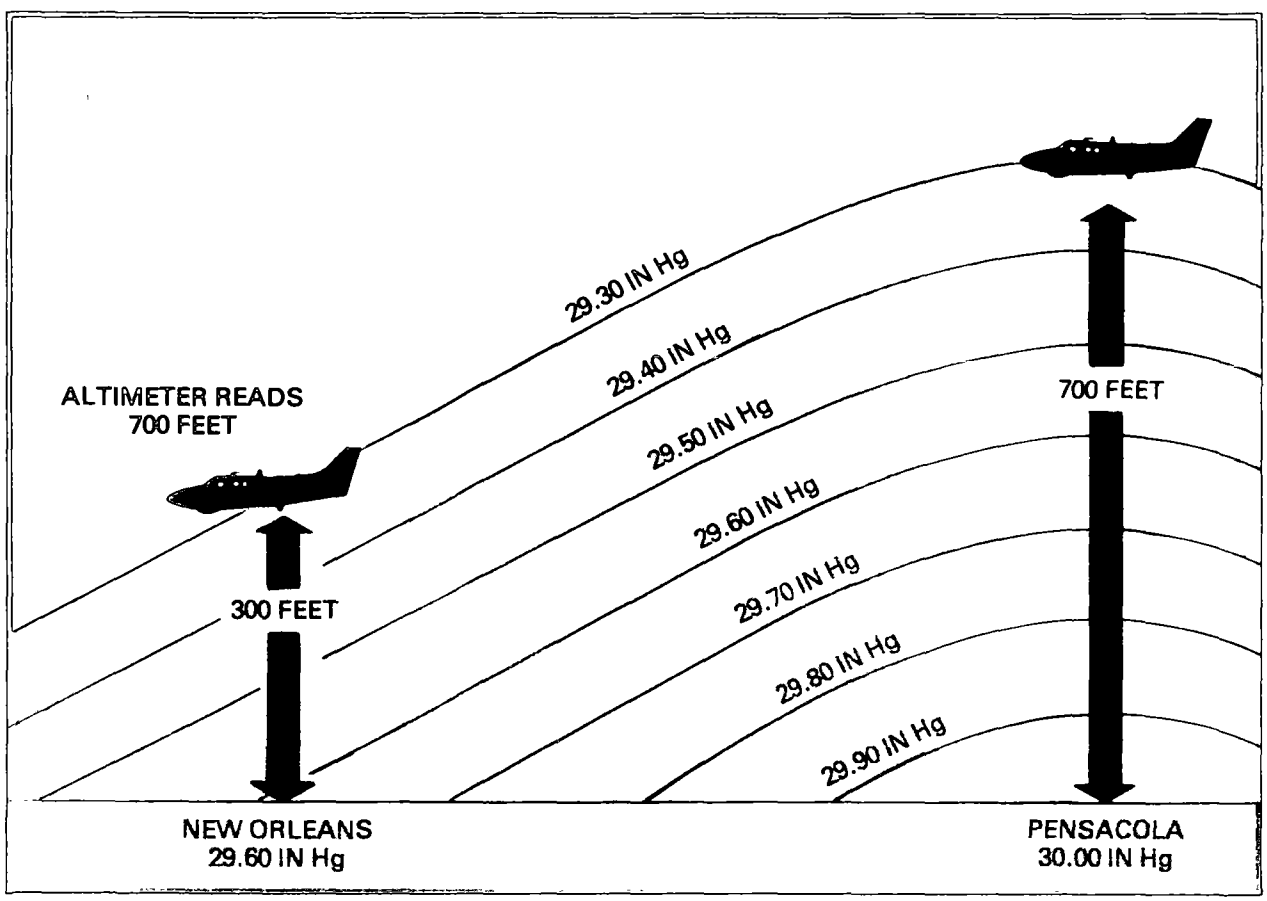
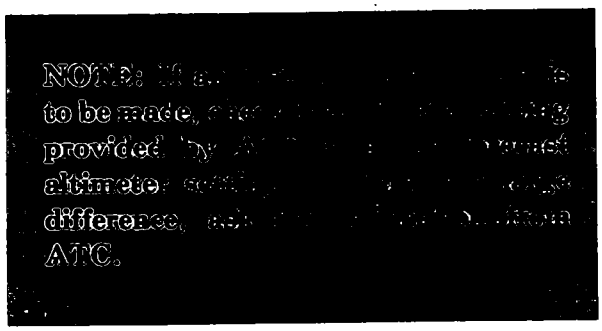


Figure 2-21. Altimeter error due to nonstandard atmospheric pressure.

(ATC) personnel. However, the altimeter setting may be requested at any time. The first altimeter setting is received prior to flight. This gives the aviator an opportunity to check the accuracy of the altimeter while still on the ground. The altimeter accuracy check will be made as follows:



(1) For rotary wing aircraft, it is best to make the check prior to starting the engine(s). This is done to eliminate the effect of any pressure changes caused by the rotor blades being in motion. For fixed wing aircraft, the check may be made either before or after starting engines.

(2) Set the current altimeter setting on the barometric scale. Then lightly tap the instrument panel near the altimeter so as to overcome any friction error within the instrument and to allow the altimeter needles to assume their corrected positions. (This is not necessary when using a counter-drum-pointer altimeter. It has an internal vibration.) Then compare the indicated altitude to a known elevation. Be sure that all needles, pointer, or drum are indicating properly. This elevation should be the one nearest the aircraft; e.g., airport elevation posted on an airport building, elevations printed in flight information publications (FLIP), or altimeter checkpoints on certain US Air Force bases. If the difference between the indicated altitude and the known elevation does not exceed 70 feet (0.07 inch Hg), the altimeter is considered reliable for flight. During flight the current altimeter settings should be placed on the barometric scale as they are received.

b. *Altimeter Setting System.* The altimeter setting provided by navigation radio stations, control towers, and other air traffic control agencies is a correction for nonstandard surface pressure only. Atmospheric pressure is measured at each station and the value obtained is corrected to sea level according to the station's surveyed elevation. Thus, the altimeter setting is a computed sea level pressure and should be considered valid only in close proximity to the station and near the surface. Nonstandard lapse rate errors may exist at all altitudes. However, at low altitudes the error is usually small.

(1) The obstruction clearance limits published for airways and instrument approaches will normally provide the necessary margin of safety for aircraft operating under instrument flight rules (IFR). Altitude separation between aircraft is maintained as long as the current altimeter setting is used. For example, in figure 2-22, aircraft A is assigned an altitude of 5,000 feet eastbound and, with the current altimeter setting applied, indicated altitude is 5,000 feet. However, due to nonstandard conditions aloft, actual altitude is only 4,700 feet. Aircraft B is assigned an altitude of 6,000 feet westbound and, with the current altimeter

setting applied, the indicated altitude is 6,000 feet. The same nonstandard conditions affect aircraft B and the actual altitude is 5,700 feet. Even though both aircraft are 300 feet below indicated altitude, they will still retain a 1,000-foot vertical clearance as they approach and pass each other.

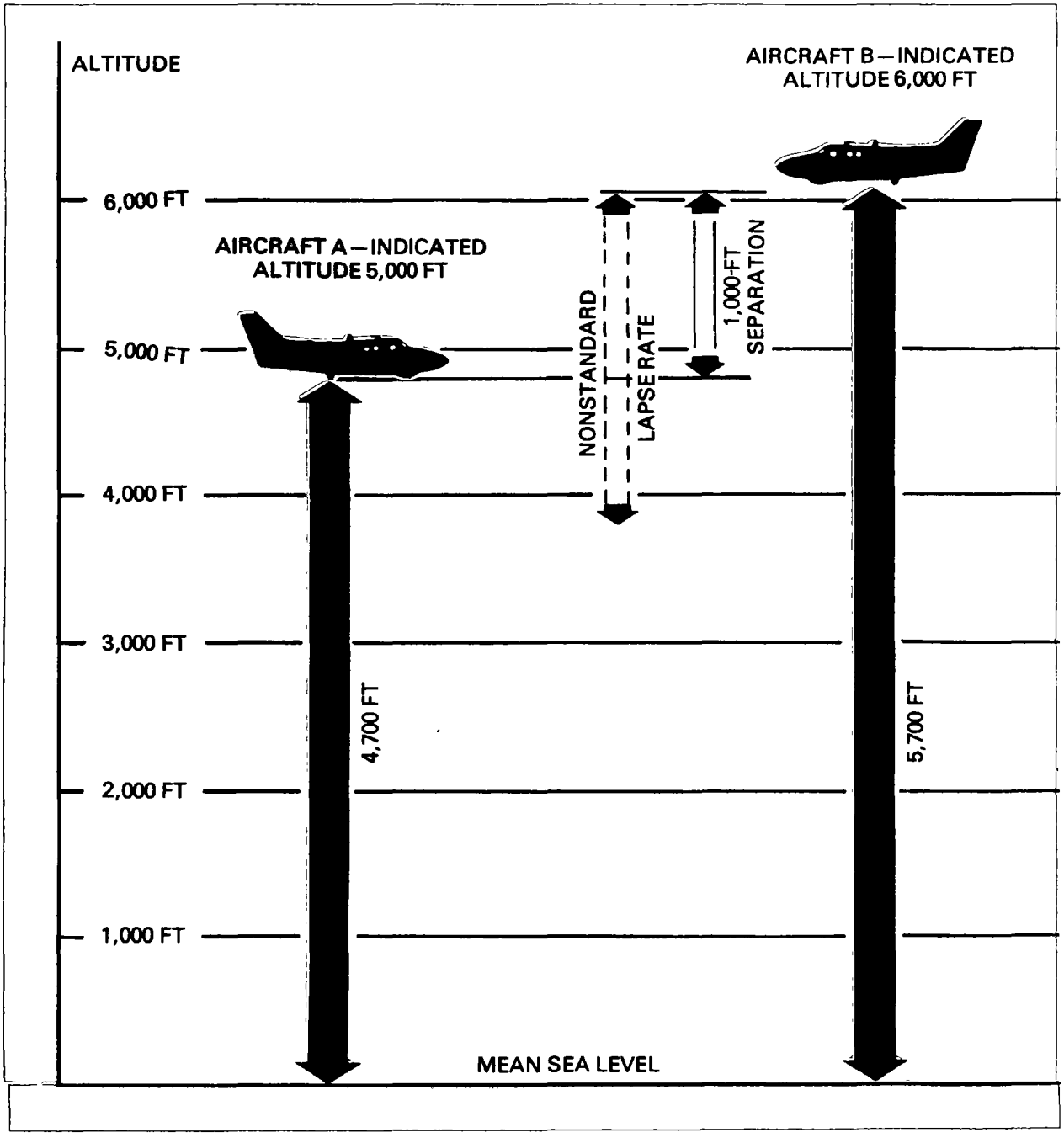


Figure 2-22. Maintaining altitude separation by using current altimeter setting.

(2) At higher altitudes, pressure and temperature deviation from standard conditions could combine to cause altimeter errors that would place the aircraft below a safe terrain clearance altitude. A *high altimeter setting* combined with a pressure level aloft which is lower than standard is particularly dangerous in mountainous terrain. For this reason, the aviator should always consult the weather forecaster to analyze pressure patterns at high altitudes. For a complete discussion of this type altimeter error, see chapter 14 of FM 1-30.

2-33. TYPES OF ALTITUDE

The following types of altitude are most often used:

a. *Indicated Altitude. Indicated altitude* is altitude as read on the dial with a current altimeter setting (sea level pressure) set into the Kollsman window (para 2-31a).

b. *Pressure Altitude. Pressure altitude* (fig 2-23) is the height measured above the 29.92 inches Hg pressure level (standard datum plane). If the Kollsman window is set to 29.92 inches Hg, the hands of the dial indicate pressure altitude. (This setting is called the *standard altimeter setting.*) In the United States, the use of pressure altitudes (standard altimeter setting) begins at 18,000 feet; these altitudes are referred to as flight levels (FL). For example, 18,000 feet = FL 180; 35,000 feet = FL 350.

c. *Absolute Altitude. Absolute altitude* (fig 2-23) is the height or altitude above the surface or terrain over which the aircraft is flying.

d. *True Altitude. True altitude* (fig 2-23) is the altitude above mean sea level.

e. *Density Altitude. Density altitude* is the altitude for which a given air density exists in the standard atmosphere. If the

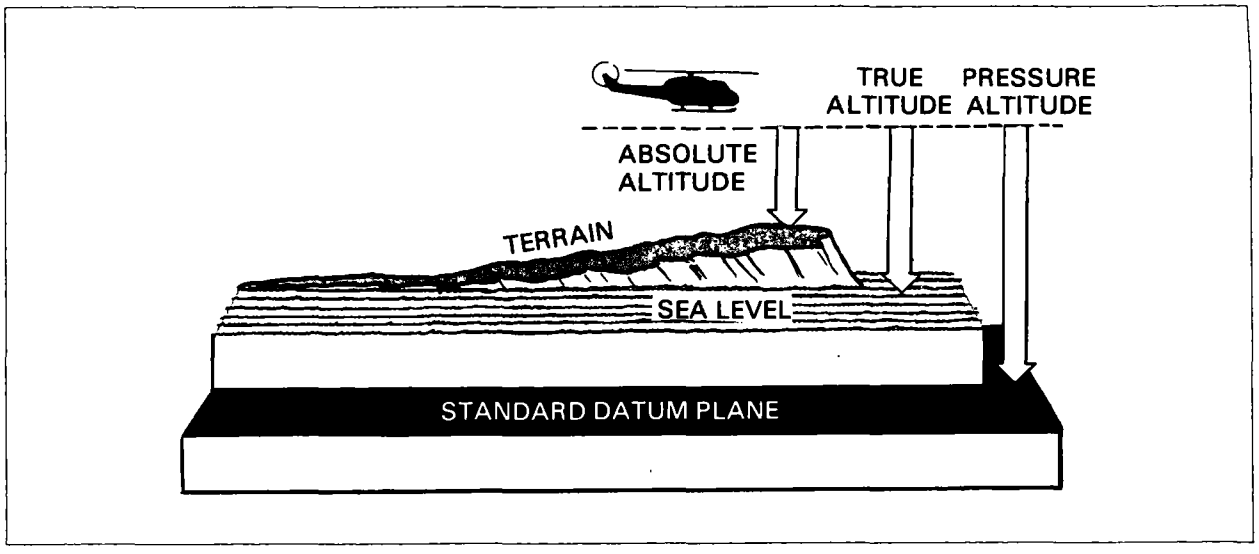


Figure 2-23. Types of altitude.

barometric pressure is lower or the temperature is higher than standard, then density altitude of the field is higher than its actual elevation. *For example,* for Denver, Colorado, with an elevation of 5,500 feet, a temperature of 110° F, and barometer reading (corrected to MSL) of 29.55 inches Hg, density altitude is about 10,000 feet. Since higher density altitude requires a greater takeoff distance and reduces aircraft performance, failure to calculate density altitude in some situations could have fatal results. Density altitudes can be obtained from many airfield towers or may be computed on the dead reckoning computer.

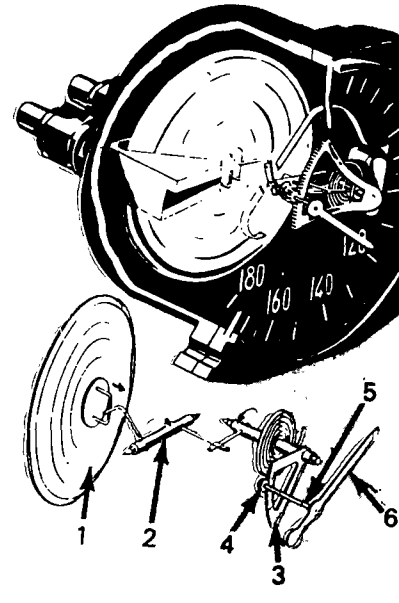
Section X. THE AIRSPEED INDICATOR

2-34. [redacted]

The airspeed indicator has a cylindrical airtight case connected to the static line. Inside the case is a small diaphragm made of phosphor bronze or beryllium copper. The diaphragm, which is very sensitive to changes in pressure, is connected firmly at one side to the impact pressure line. The needle is connected through a series of levers and gears to the free side of the diaphragm (fig 2-24).

2-35. [redacted]

The airspeed indicator is a differential pressure instrument. It measures the difference between the pressure in the impact pressure line and the pressure in the static pressure line. The two pressures are equal when the aircraft is stationary on the ground; but movement through the air causes the pressure in the impact line to become greater than the pressure in the static line. The diaphragm, being connected directly to the impact pressure line, will expand due to increased impact pressure. The dial is scaled so that the needle will indicate this pressure differential in knots.



PRINCIPAL PARTS

(1) Diaphragm
(2) Rocking Shaft
(3) Sector
(4) Pinion
(5) Tapered Staff
(6) Pointer

Figure 2-24. Cutaway view of the airspeed indicator with component parts.

2-36. KINDS OF AIRSPEEDS

There are three kinds of airspeeds—*indicated, calibrated,* and *true.*

a. *Indicated Airspeed. Indicated airspeed* is the airspeed read directly from the indicator.

b. *Calibrated Airspeed. Calibrated airspeed* is indicated airspeed corrected for instrument installation error. This error is caused by the difference in the static pressure at the pitot head and the static pressure at the static vents. The error is usually small and may be computed by reference to the appropriate aircraft operator's manual.

c. *True Airspeed. True airspeed* is calibrated airspeed corrected for error due to air density (altitude and temperature). This may be computed on the dead reckoning computer.

Section XI. THE VERTICAL SPEED INDICATOR

2-37. CONSTRUCTION

The vertical speed indicator (A, fig 2-25) has a sealed case connected to the static pressure line through a calibrated leak. Inside the case is a diaphragm similar to that in the airspeed indicator (para 2-34). This diaphragm is connected directly to the static pressure line. A system of levers and gears connects the diaphragm to the indicating needle on the face of the instrument (B, fig 2-25). The vertical speed indicator contains a mechanism which enables it to compensate automatically for changes in air temperature.

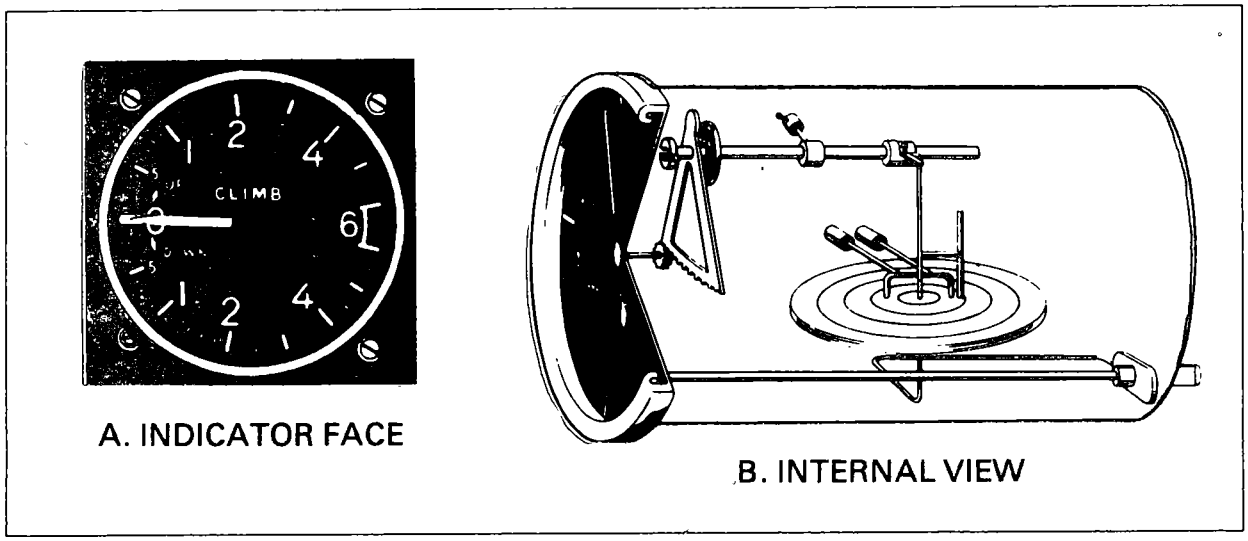


Figure 2-25. The vertical speed indicator.

Although the vertical speed indicator operates entirely from static pressure, it is a differential pressure instrument. The differential pressure is established between the instantaneous static pressure in the diaphragm and the trapped static pressure within the case. When the aircraft starts a climb, the pressure in the diaphragm decreases in ratio to the reduction in atmospheric pressure. The calibrated leak retards the pressure change to the instrument case. This causes the diaphragm to contract, causing the needle to indicate an ascent. The leak in the case is calibrated so that it maintains a definite ratio between the pressure in the diaphragm and the pressure in the case as long as a constant rate of climb is maintained. When the aircraft levels off, the calibrated leak requires 6 to 9 seconds to equalize the two pressures and to allow the needle to return to zero. This causes a lag of 6 to 9 seconds in the instrument. When the aircraft is descending, the pressure inside the diaphragm is increasing and the calibrated leak again maintains a constant relation between the two pressures.

The vertical speed indicator gives the rate at which the aircraft is climbing or descending (or indicates level flight). These indications are not reliable in extremely rough air or when the attitude of the aircraft is constantly changing. This is due, in part, to the lag in the instrument. The instrument can be used for indications of pitch attitude if a thorough understanding of its lag is considered in interpreting the indications.

The needle of the vertical speed indicator should indicate zero while the aircraft is on the ground or maintaining a constant altitude; any reading other than zero indicates a need for adjustment. This adjustment can be made by using a small screwdriver to turn the screw in the lower left corner of the instrument.

The instantaneous vertical speed indicator can be identified by the letters "IVSI" that appear on the dial. Compared to the conventional vertical speed indicator, this instrument has no apparent lag. The instantaneous vertical speed indicator is similar in construction to the conventional vertical speed indicator (para 2-37); it differs from this indicator by the addition of two accelerometers which generate pressure differences whenever there is a change in the normal acceleration of the aircraft. The pressure differences are transmitted to the sensitive diaphragm by pneumatic circuits. A velocity is added, as necessary, to the pressure leak velocity to obtain the total nearly instantaneous vertical speed indication. As the pressure-leak component approaches the actual speed, the integrated component fades out.

a. The sum of the pressure-leak and accelerometer velocities is the total vertical airspeed, provided the normal axis of the aircraft is within about 30° of the vertical.

b. Since the accelerometers are not vertically stabilized, some error is generated in turns. If a zero indication is maintained on the instantaneous vertical speed indicator when entering a turn, some loss in altitude will be encountered. A corresponding gain in altitude will result when recovering from a turn. The instantaneous vertical speed indicator should not be used for directly controlling vertical speed when rapidly banking in excess of 40°. However, the indicator is not affected once in a steady turn.

c. The fadeout of acceleration in a steady turn, when a turn has been started and the accompanying change in normal acceleration has been completed, occurs because the accelerator masses will settle to new balance points corresponding to the normal acceleration maintained in the turn. In establishing a 30-degree bank, altitude deviation should not exceed 90 feet while maintaining the instantaneous vertical speed indicator at 0. In more steeply banked turns, the turn error rapidly increases with bank angle.

CHAPTER 3

POWER, PITCH ATTITUDE, AND BANK CONTROL THROUGH INSTRUMENTS FOR FIXED AND ROTARY WING AIRCRAFT

Section I. GENERAL

3-1. INTRODUCTION

In instrument flying, attitude requirements are determined by interpretation of the instrument indications within the aircraft. The attitude of an aircraft is controlled by movement around its lateral, longitudinal, and vertical axes (fig 3-1 and 3-2).

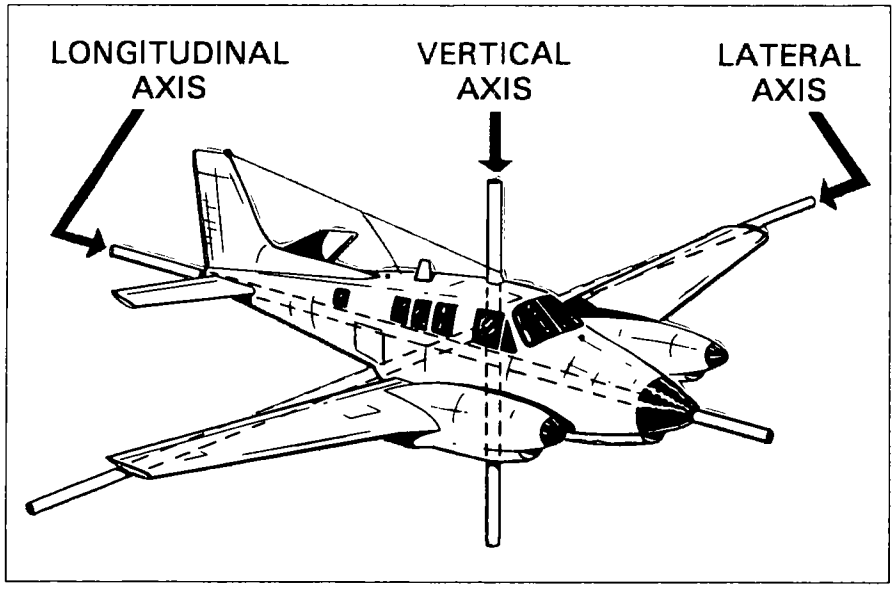


Figure 3-1. Axes of movement.

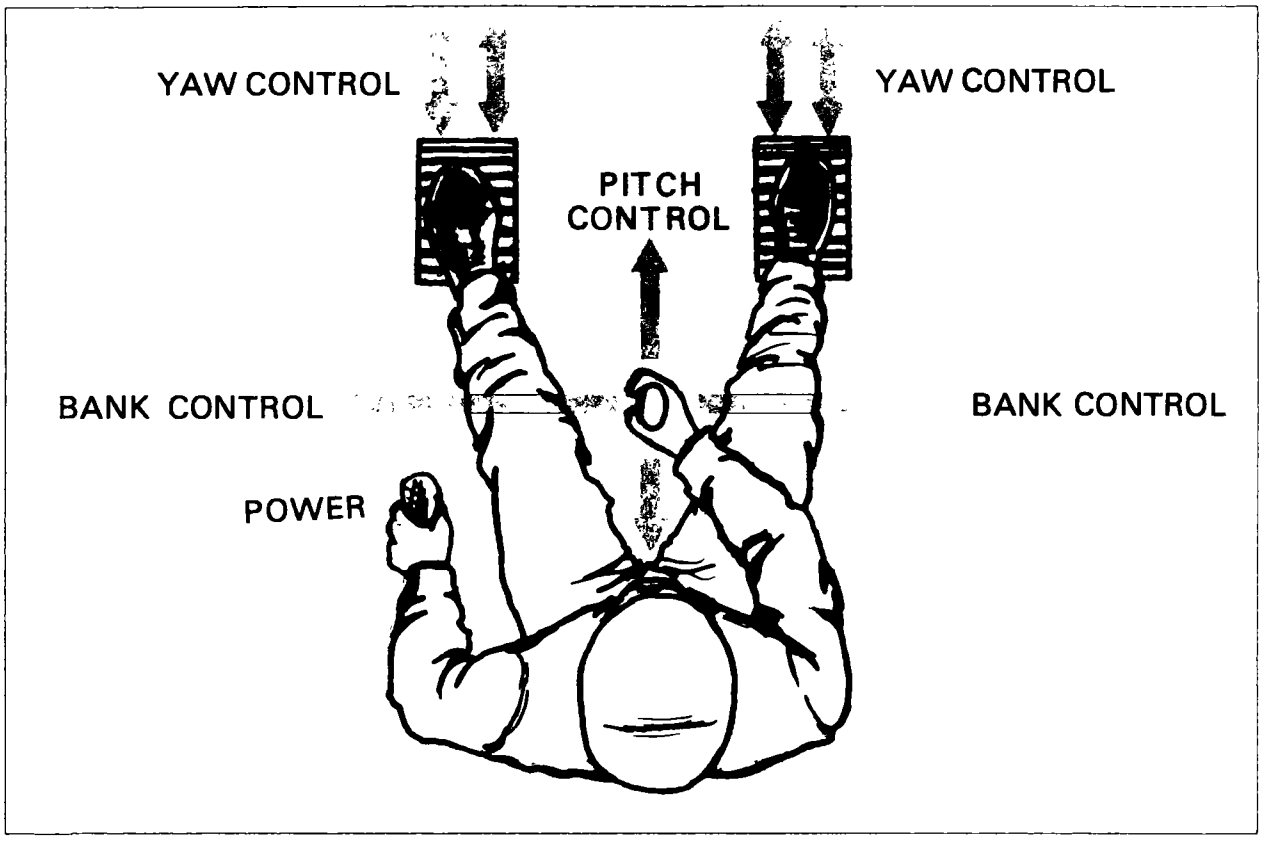


Figure 3-2. Power, pitch attitude, and bank control.

3-2. CROSS-CHECKING

Observing and interpreting two or more instruments to determine the attitude and performance of an aircraft is called *cross-checking*.

a. Although no specific method of cross-checking is recommended, those instruments which give the best information for controlling the aircraft in any given maneuver should be used. The important instruments are the ones that give the most pertinent information for any particular phase of the maneuver, and are usually the instruments that should be held at a constant indication. The remaining instruments should be used to aid in maintaining the important instruments at the desired indications. This is also true in using the emergency panel.

b. Cross-checking is mandatory in instrument flying. In visual flight, a level attitude can be maintained by outside references. However, even then the altimeter must be checked to determine if altitude is being maintained.

[redacted]

a. *General.* Proper trim technique is essential to smooth and accurate instrument flying. The aircraft should be properly trimmed while executing a maneuver. The degree of flying skill which an aviator will ultimately develop depends largely upon how well he learns to keep the aircraft trimmed.

b. *Fixed Wing.* A fixed wing aircraft is correctly trimmed when it is maintaining a desired attitude with all control pressures neutralized. By relieving all control pressures, the aviator will find it much easier to maintain the aircraft in a certain attitude. This will allow him more time to devote to the navigation instruments and to additional cockpit duties. An aircraft is placed in trim by applying control pressure(s) to establish a desired attitude and then adjusting the trim so that the aircraft will maintain that attitude when the flight controls are released. Trim the aircraft for coordinated flight by centering the ball of the turn-and-slip indicator. Move the rudder trim in the direction the ball is displaced from center. Aileron trim may then be adjusted to maintain a wings-level attitude. Differential power control on multiengine aircraft is an additional factor affecting coordinated flight. When possible, use balanced power/thrust to aid in maintaining coordinated flight. Changes in attitude, power, or configuration may require trim adjustments. Use of trim alone to establish a change in aircraft attitude usually results in erratic aircraft control. Smooth and precise attitude changes are best attained by a combination of control pressures and subsequent trim adjustments. The trim controls are aids to smooth aircraft control.

c. *Rotary Wing.* Maintaining trim in rotary wing aircraft is accomplished by a continuing cross-check of the instruments and the use of any trim devices on the aircraft. See paragraphs 3-16b and 3-23d for trim procedures.

Section II. POWER CONTROL

[redacted]

Power produces thrust and gives motion to the wings/rotor(s), thus creating lift. Sufficient power, combined with the appropriate attitude of the wing, overcomes the forces of gravity, drag, and inertia, and results in the desired performance of the aircraft.

[redacted]

Army aircraft (both fixed and rotary wing) are powered by a variety of powerplants. Each powerplant has certain instruments, available to the aviator, that indicate the amount of power that is being applied in the operation of the aircraft. During instrument flight, these instruments must be used by the aviator in making the required power adjustments.

If airspeed is maintained constant by pitch attitude adjustments, there will be a resulting pitch attitude of the aircraft where a certain power setting will result in level flight (A, fig 3-3). Then, if power is increased, there will be a requirement for a pitch attitude adjustment upward to maintain a constant airpeed and a climb will result (B, fig 3-3). If the power setting is decreased, the pitch attitude must be decreased in order to maintain a constant airspeed and a descent will result (C, fig 3-3).

A constant altitude is maintained by minor pitch attitude adjustments and the desired airspeed is maintained by power adjustments as necessary. After the altitude is stabilized and the desired airspeed is established, any deviation from altitude will result in a change in the airspeed as long as the altitude is changing. When the altitude is once again stabilized, the airspeed will return to its previous indication provided the power is maintained at the previous setting. If airspeed is high due to loss of altitude, the excess airspeed may be used by an upward pitch adjustment in returning the aircraft to the desired altitude and airspeed. Conversely, with a gain in altitude and an accompanying loss of airspeed, the excess altitude may be used by a downward pitch attitude adjustment in returning the aircraft to the desired altitude and airspeed. When the airspeed is as desired but the altitude is not as desired, pitch adjustments may be used to make small corrections in altitude while allowing the airspeed to change temporarily. In figure 3-4, the aircraft at A-1 will be returned to 4,000 feet altitude and 140 knots airspeed by the action taken in B. Aircraft A-2 will be returned to 4,000 feet altitude and 140 knots airspeed by the action taken in C. In both examples, note that there was a temporary airspeed change until the aircraft was once again back to the desired altitude. Whenever a combination of high altitude and airspeed or low altitude and airspeed exist, a power adjustment is required to more easily make the altitude adjustment and to keep the airspeed near that desired.

When power is changed to adjust airspeed, it may cause changes in the attitude of the aircraft around some or all axes of movement. The amount and direction of movement will depend on how much or how rapidly the power is changed, whether the aircraft is single-engined or multiengined, and whether the aircraft is fixed wing or rotary wing. As the airspeed is changing, the pitch attitude must be adjusted as necessary to maintain the desired attitude for the maneuver being executed. The bank must be adjusted as necessary to maintain the desired heading or to maintain a desired rate of turn, and the rudder must be used as necessary to maintain coordinated flight. Trim must be adjusted as control pressures indicate a

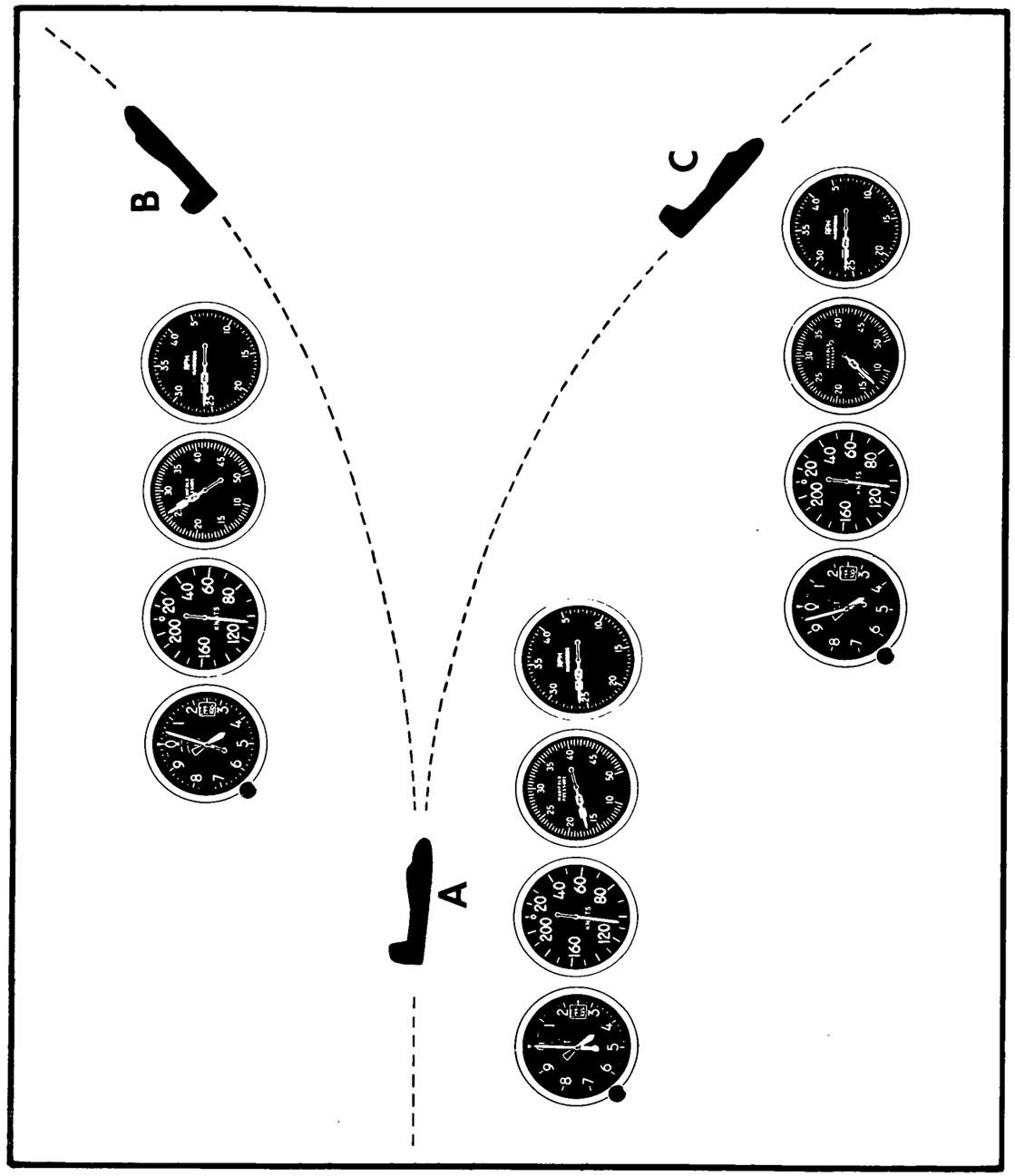


Figure 3-3. Effects of power changes while maintaining constant airspeed.

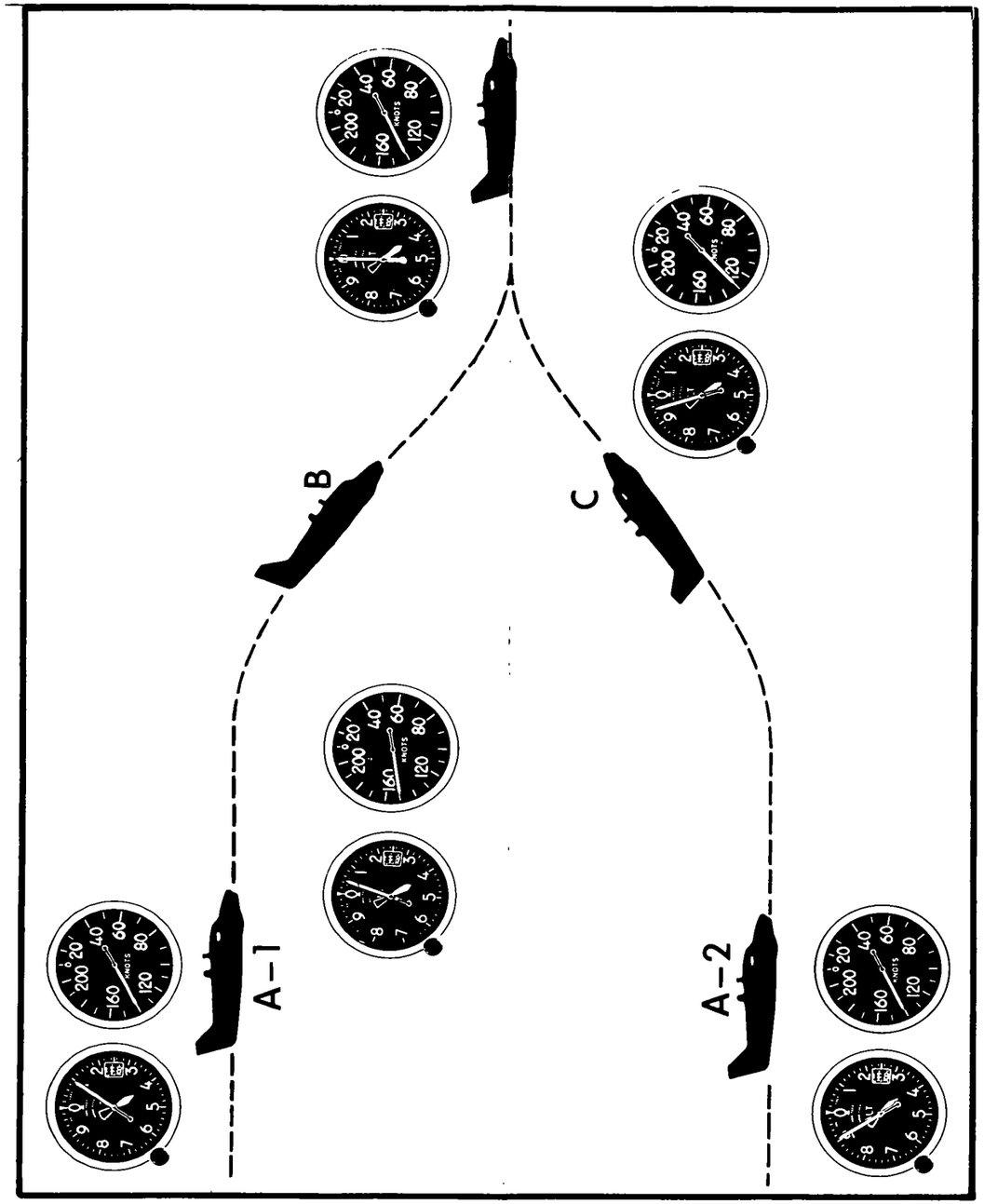


Figure 3-4. Airspeed converted to altitude and vice versa.

change is needed. The effect on pitch attitude and airspeed caused by power changes during level flight is illustrated in figure 3-5.

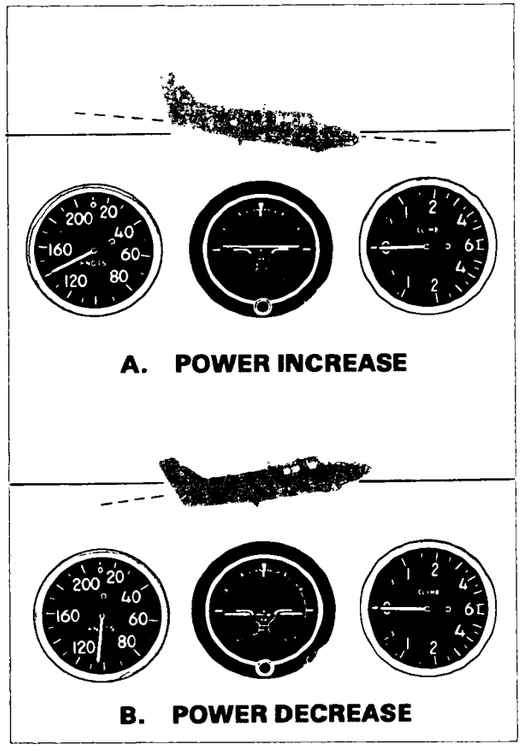


Figure 3-5. Maintaining a constant altitude/ power variable.

3-9. POWER CONTROL

When large airspeed changes are desired, such as reducing from cruise flight to traffic pattern airspeed, the change can be attained in a shorter period of time if the power is reduced to a setting lower than that which has been recommended to maintain the pattern airspeed. Conversely, for making a change from a lower to a higher speed, the power may be advanced to a setting which is higher than that recommended for the higher speed. In both cases, as the airspeed approaches that which is desired, the power must be adjusted to the recommended setting to maintain it.

3-10. CROSS-CHECK OF POWER INSTRUMENTS

During or immediately after adjusting the power control(s), the power instuments should be cross-checked to see if the power adjustment is as desired. Whether the need for a power adjustment is indicated by another instrument or instruments, or if desired by the aviator, it is made by reference to the power instruments.

Section III. PITCH ATTITUDE CONTROL

3-11. GENERAL

The *pitch attitude* control of an aircraft is the angular relationship between the longitudinal axis of the aircraft and the actual horizon (fig 3-6). The pitch attitude control instruments are the altimeter, attitude indicator, vertical speed indicator, and airspeed indicator (fig 3-7). The attitude indicator displays a direct indication of the pitch attitude of the aircraft. The other pitch attitude control instruments indicate indirectly the pitch attitude of the aircraft.

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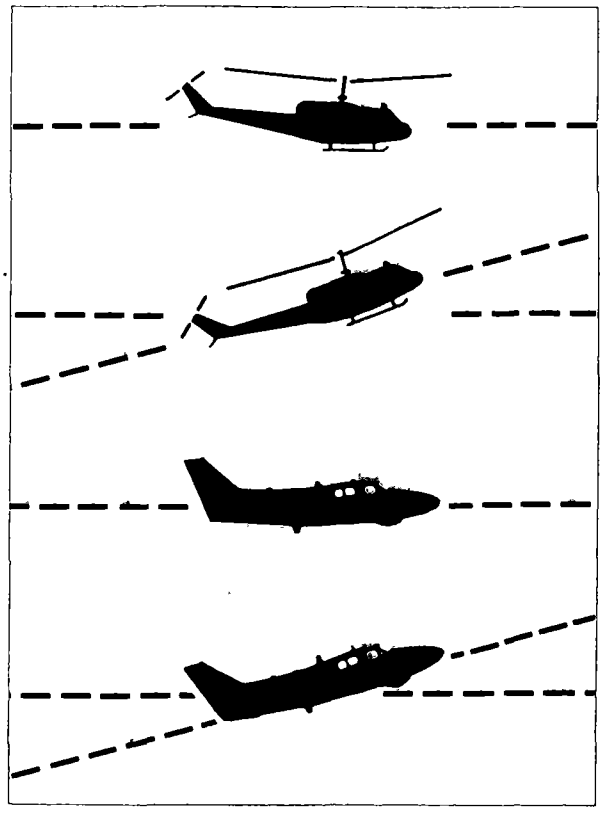


Figure 3-6. Pitch attitude.

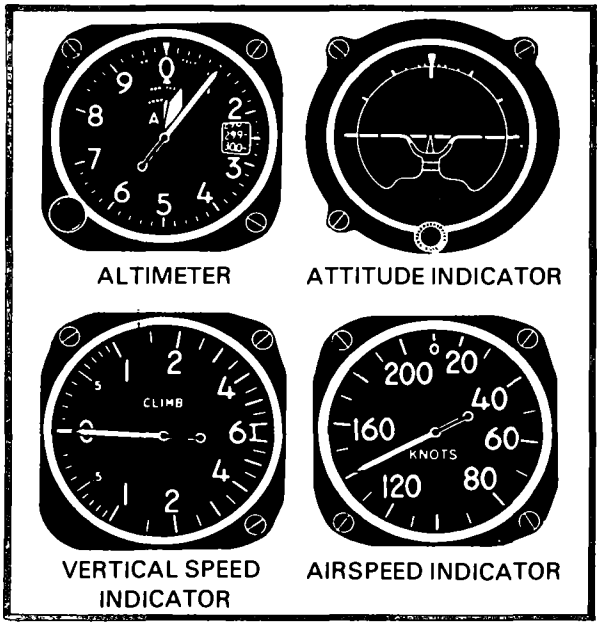


Figure 3-7. Pitch attitude indicating instruments.

ATTITUDE INDICATOR

The attitude indicator gives a direct and immediate indication of the pitch attitude of the aircraft. The aircraft controls are used to position the miniature aircraft in relation to the horizon bar or horizon line for any pitch attitude required (fig 3-8).

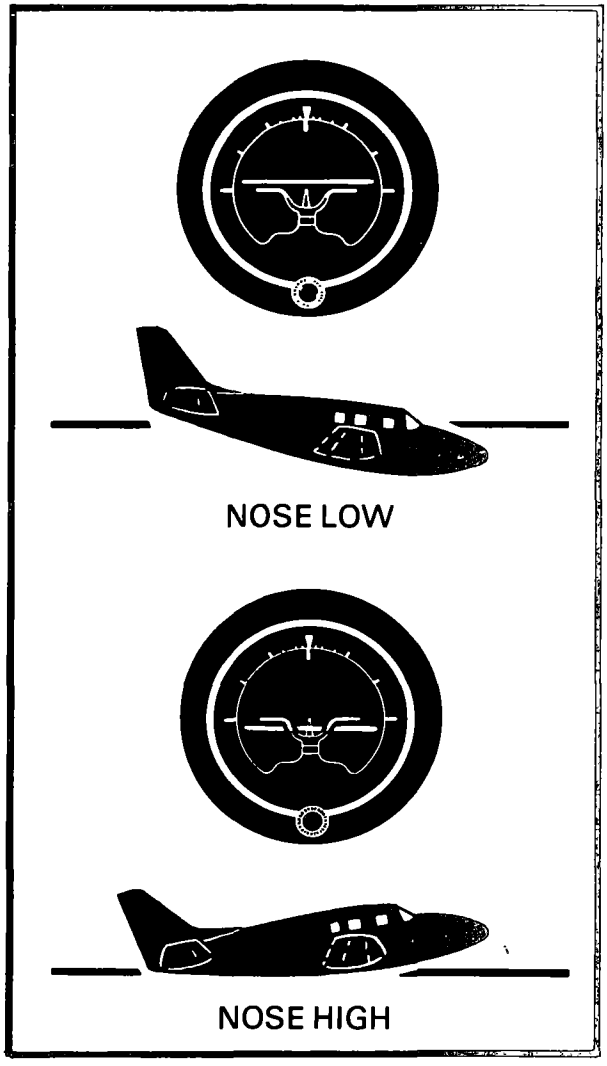


Figure 3-8. Attitude indicator showing indications of pitch attitude.

a. The miniature aircraft should be placed in the proper position in relation to the horizon bar or horizon line prior to takeoff. The aviator will refer to the aircraft operator's manual to determine this position. As soon as practicable in level flight and at desired cruise airspeed, the miniature aircraft should be moved to a position that alines the wings of the miniature aircraft in front of the horizon bar or horizon line. This adjustment may be made anytime that varying loads or other conditions indicate that it is needed. Otherwise, the position of the miniature aircraft should not be changed for flight at other than cruise speed. This is to insure that the attitude indicator will display a true picture of pitch attitude in all maneuvers.

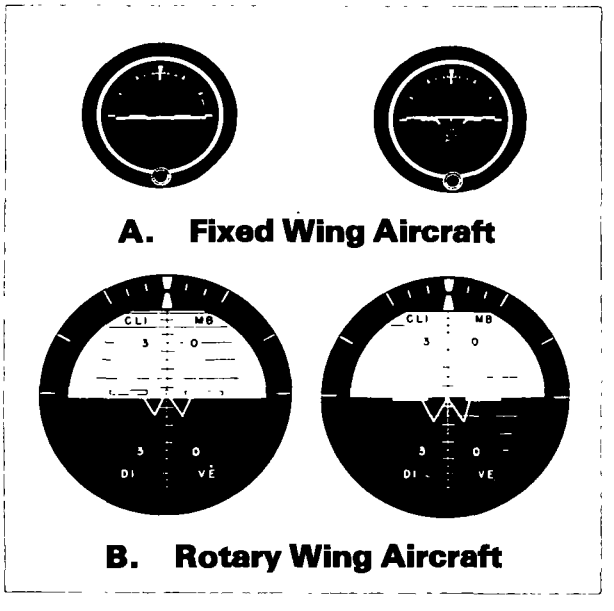


Figure 3-9. Initial pitch correction.

b. When using the attitude indicator in applying pitch attitude corrections, control pressure should be extremely light. Movement of the horizon bar above or below the miniature aircraft of the attitude indicator in fixed wing aircraft should not exceed one-half the bar width (A, fig 3-9); in rotary wing aircraft, movement should not exceed one bar width (B, fig 3-9). If further change is required, an additional correction of not more than one-half the width of the horizon bar will normally counteract any deviation from normal flight.

3-13. THE ALTIMETER

If the aircraft is maintaining level flight, the altimeter needles will maintain a constant indication of altitude. If the altimeter indicates a loss of altitude, the pitch attitude must be adjusted upward to stop the descent. If the altimeter indicates a gain in altitude, the pitch attitude must be adjusted downward to stop the climb (fig 3-10). The altimeter can also indicate the pitch attitude in a climb or descent by how rapidly the needles move. A minor adjustment in pitch attitude may be made to control the rate at which altitude is gained or lost.

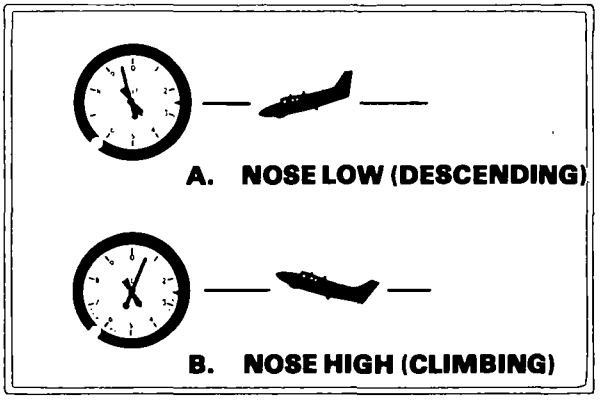


Figure 3-10. Altimeter indications of pitch attitude.

3-14. THE VERTICAL SPEED INDICATOR

a. In flight at a constant altitude, the vertical speed indicator (sometimes referred to as vertical velocity indicator or rate-of-climb indicator) will remain at a zero position. If the needle moves below the zero position, the pitch attitude must be adjusted upward to stop the descent and return to level flight. If the needle moves above the zero position, the pitch attitude must be adjusted downward to stop the climb and return to level flight. Prompt adjustments to the changes in the indications of the vertical speed indicator may prevent any significant change in altitude (fig 3-11). Turbulent air will cause fluctuations of the needle about the zero position. In such conditions, the average of the fluctuations should be considered as the correct reading. Reference to the altimeter will be of help in turbulent air, since it is not as sensitive as the vertical speed indicator. The amount of vertical speed indicated or the rate at which the needle moves away from the zero position indicates the amount of pitch attitude adjustment that will be required to return the needle to zero and stop any altitude change. For example, a large deviation of the needle from zero or a rapid movement away from the zero position indicates that a large pitch attitude adjustment will be required to return the needle to zero position. When using the vertical speed indicator to make corrections back to the desired altitude, the correction must not be too large and cause the aircraft to overshoot the desired altitude, nor should it be so small that the return to altitude is unnecessarily prolonged. As a guide, the pitch attitude change should produce a rate of change on the vertical speed indicator of approximately twice the size of the altitude deviation. For example, if the aircraft is 100 feet off the desired altitude, a 200 feet-per-minute (fpm) rate of correction would be used.

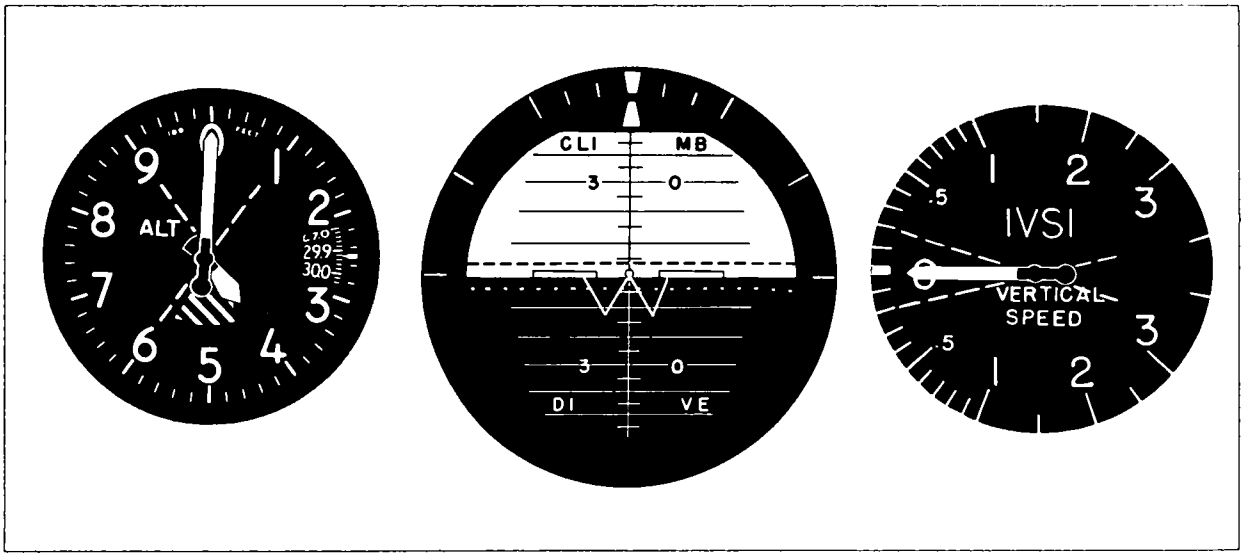


Figure 3-11. The vertical speed indicator as a pitch- indicating instrument.

b. During climbs or descents, the vertical speed indicator is used to change the altitude at a desired rate. Pitch attitude and power adjustments are made as necessary to maintain the desired rate of climb or descent on the vertical speed indicator.

c. When pressure is applied to the controls and the vertical speed indicator shows a rate exceeding 200 fpm from that desired, overcontrolling is indicated. *For example,* if attempting to regain lost altitude at the rate of 500 fpm, a reading of more than 700 fpm will indicate overcontrolling. The initial movement of the needle indicates the trend of the vertical movement of the aircraft. The period of time necessary for the vertical speed indicator to reach its maximum point of deflection after a correction has been made is referred to as *lag.* The lag is proportional to the speed and magnitude of the pitch change. In fixed wing aircraft, overcontrolling may be reduced by relaxing pressure on the controls, which allows the pitch attitude to neutralize itself. In some rotary wing aircraft with servo-assisted controls, no control pressures are apparent. Under this condition, overcontrolling can be reduced by reference to the attitude indicator.

d. Some aircraft are equipped with an *instantaneous vertical speed indicator* (IVSI). (The letters "IVSI" appear on the face of the indicator.) This instrument assists in interpretation by instantaneously indicating the rate of climb or descent.

e. Occasionally, the vertical speed indicator is slightly out of calibration and will indicate a slight climb or descent when the aircraft is in level flight. If readjustment cannot be accomplished, the error in the indicator should be considered when the instrument is used for pitch control. For example, an improperly set vertical speed indicator may indicate a descent of 100 fpm when the aircraft is in level flight. Any deviation from this reading would indicate a change in pitch attitude.

3-15. THE AIRSPEED INDICATOR

The *airspeed indicator* gives an indirect reading of the pitch attitude. With a constant power setting and a constant altitude, the aircraft is in level flight and the airspeed remains constant. If the airspeed increases, the pitch attitude has lowered and should be raised. If the airspeed decreases, the pitch attitude has moved higher and should now be lowered (fig 3-12). A rapid change in airspeed indicates a large change in pitch; a slow change in airspeed indicates a small change in pitch. Although the airspeed indicator is used as a pitch instrument, it may be used in level flight for power control. Changes in pitch are reflected immediately by a change in airspeed. There is very little lag in the airspeed indicator.

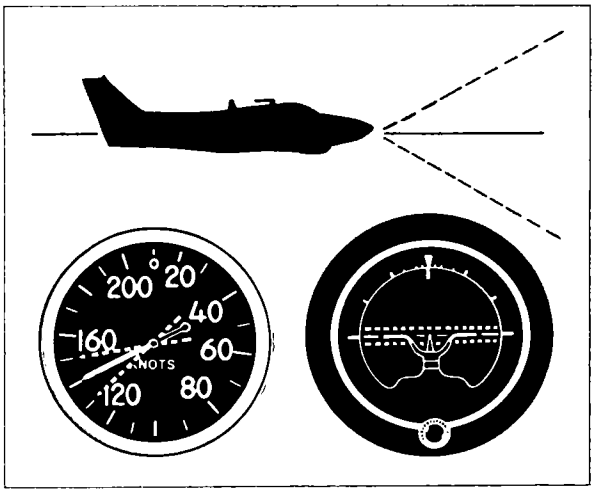


Figure 3-12. The airspeed indicator as a pitch attitude instrument.

[redacted]TRIM

Incorrect setting of pitch attitude trim (fig 3-13) may result in a nose-high or a nose-low pitch attitude unless corrective pressures are maintained.

a. Proper pitch attitude trim for fixed wing aircraft may be made as follows:

(1) Establish desired attitude with control pressure.

(2) Relieve control pressure by application of trim while maintaining attitude.

(3) Repeat above procedures as necessary until the aircraft maintains an attitude without constant pressure on the control.

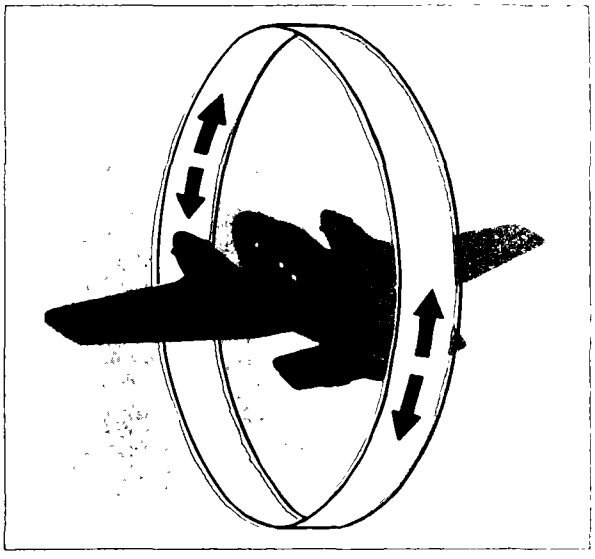


Figure 3-13. Pitch attitude trim.

b. Some rotary wing aircraft have provisions for pitch attitude trim and relief of control pressures. Pitch trim adjustments on these aircraft should be made as follows:

(1) Press force trim button or control centering release button.

(2) Establish desired pitch attitude.

(3) Release force trim button or control centering release button.

(4) Repeat (1) through (3) above, as necessary.

[redacted]

a. The altimeter is an important instrument for indicating pitch attitude in level flight except when used in conditions of exceptionally strong vertical currents such as thunderstorms. With proper power settings, any of the pitch attitude instruments can be used to hold a reasonably level flight attitude; however, only the altimeter will give the exact altitude information.

b. Regardless of which pitch attitude control instrument indicates a need for a pitch attitude adjustment, the attitude indicator, if available, should be used to make the adjustment.

3-18. COMMON ERRORS IN PITCH ATTITUDE CONTROL

Some common errors in pitch attitude control are—

a. Overcontrolling.

b. Improper use of power.

c. Failure to cross-check the pitch attitude instruments adequately and to take proper corrective action when need for a change in pitch attitude is indicated.

Section IV. BANK-ATTITUDE CONTROL

3-19. BANK-ATTITUDE CONTROL TO PRODUCE BALANCED STRAIGHT FLIGHT

The *banking attitude* (fig 3-14) of an aircraft is the angular relationship of the lateral axis of the aircraft to the actual horizon. To maintain a straight course in visual flight, the wings (rotor(s)) of the aircraft must be kept level with the actual horizon. In balanced flight, any deviation from a wings-level attitude produces a turn. During actual or simulated instrument conditions, the miniature aircraft and horizon bar of the attitude indicator are substituted for the real aircraft and the actual horizon, and the banking attitude is accurately indicated. Instruments which indicate banking attitude are the attitude indicator, the heading indicator, and the turn-and-slip indicator (fig 3-14).

3-20. THE ATTITUDE INDICATOR

The banking attitude is shown directly on the attitude indicator (fig 3-15). Banking is shown by the miniature aircraft wings assuming an angle in relation to the horizon bar and by the bank index pointer moving from the zero position. The bank index pointer will indicate the angle of bank of the aircraft by assuming a position in relation to the angle of bank reference marks at the top of the instrument face. The aviator must determine the direction of banking by reference to the miniature aircraft. The bank index pointer moves in a direction opposite to the bank. In coordinated flight, maintaining the bank index pointer at the zero position will prevent banking.

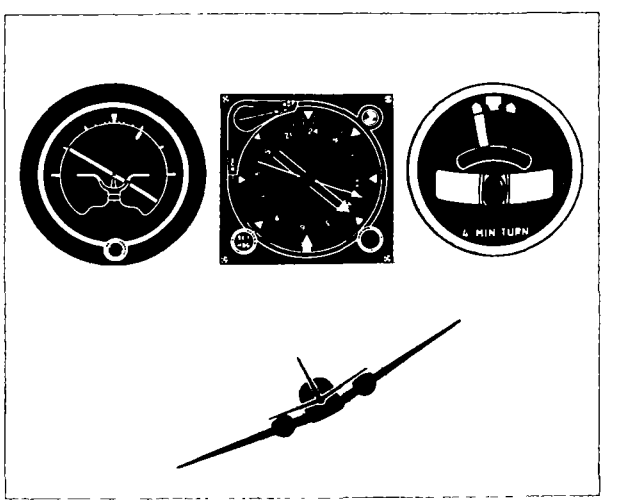


Figure 3-14. Bank-attitude instruments.

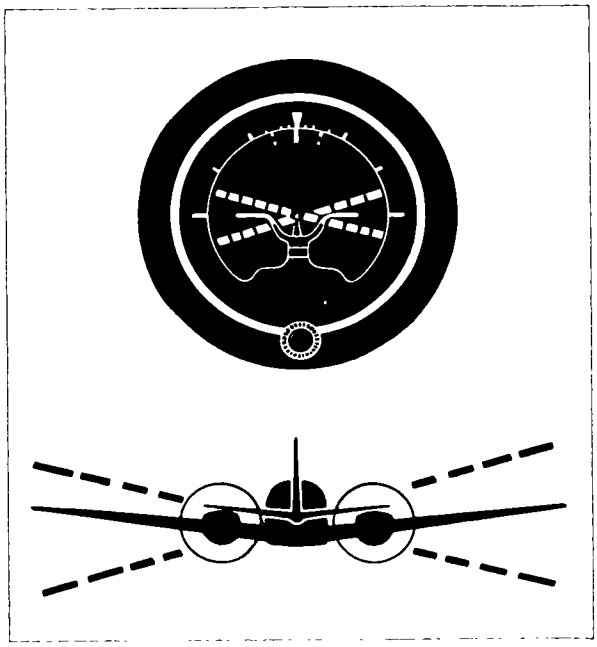


Figure 3-15. The attitude indicator as a bank-attitude instrument.

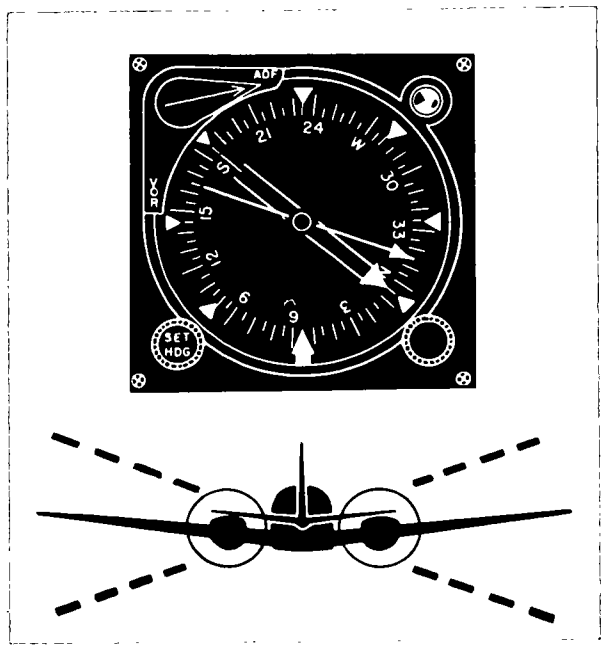


Figure 3-16. The heading indicator as a bank-attitude instrument.

3-21. THE HEADING INDICATOR

The heading indicator gives an immediate indication of turning (fig 3-16). In balanced or coordinated flight, the indication of a turn means that the aircraft is banking in the direction of the turn, and that the bank must be corrected if the turn is to be stopped. The heading indicator also indicates indirectly the amount of bank the aircraft has assumed. If the heading is changing slowly, the amount of banking is small. If it is moving rapidly, the amount of banking is large. If a fixed wing aircraft continues to turn after the banking is corrected, the rudder trim should be checked for a possible resetting.

3-22. THE TURN-AND-SLIP INDICATOR

When the attitude indicator is not available, the heading indicator is used for bank attitude control in straight flight. However, for making turns, the turn needle must be used.

a. *Turn Needle.* The turn needle indicates both direction and rate of turn. In balanced or coordinated flight, the aircraft is not banking if the turn needle is centered. If the needle is displaced from center, the aircraft is banking and turning in the direction of the displacement. Recentering the needle with smooth and coordinated control movements will remove any banking attitude and the aircraft will fly straight. Any deviation from the exact

center position must be promptly re-centered to prevent turning (fig 3-17). Accurate interpretation of the needle position requires close observation. In turbulent air, the needle will oscillate from side to side. Accurate interpolation of these fluctuations must be made to detect actual turning. If any deflection is equal on both sides of center, the aircraft is flying straight. If the distance of deflection is greater on one side than the other, the aircraft is turning in the direction of the greater deflection.

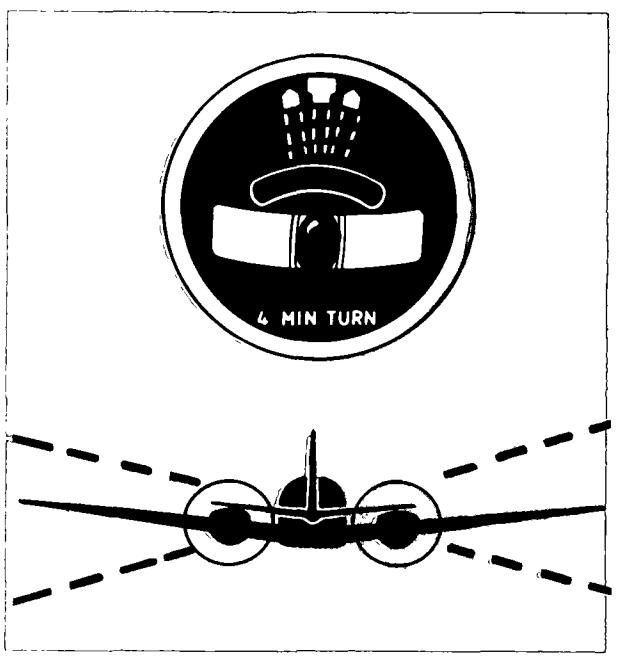


Figure 3-17. The turn-and-slip indicator as a bank-attitude instrument.

b. *Turn-and-Slip Indicator Ball.* Although the ball is combined with the turn indicator as one unit, it is a separate and independent instrument, with its own specific function. The two parts of the turn-and-slip indicator are, however, normally read and interpreted together. If the

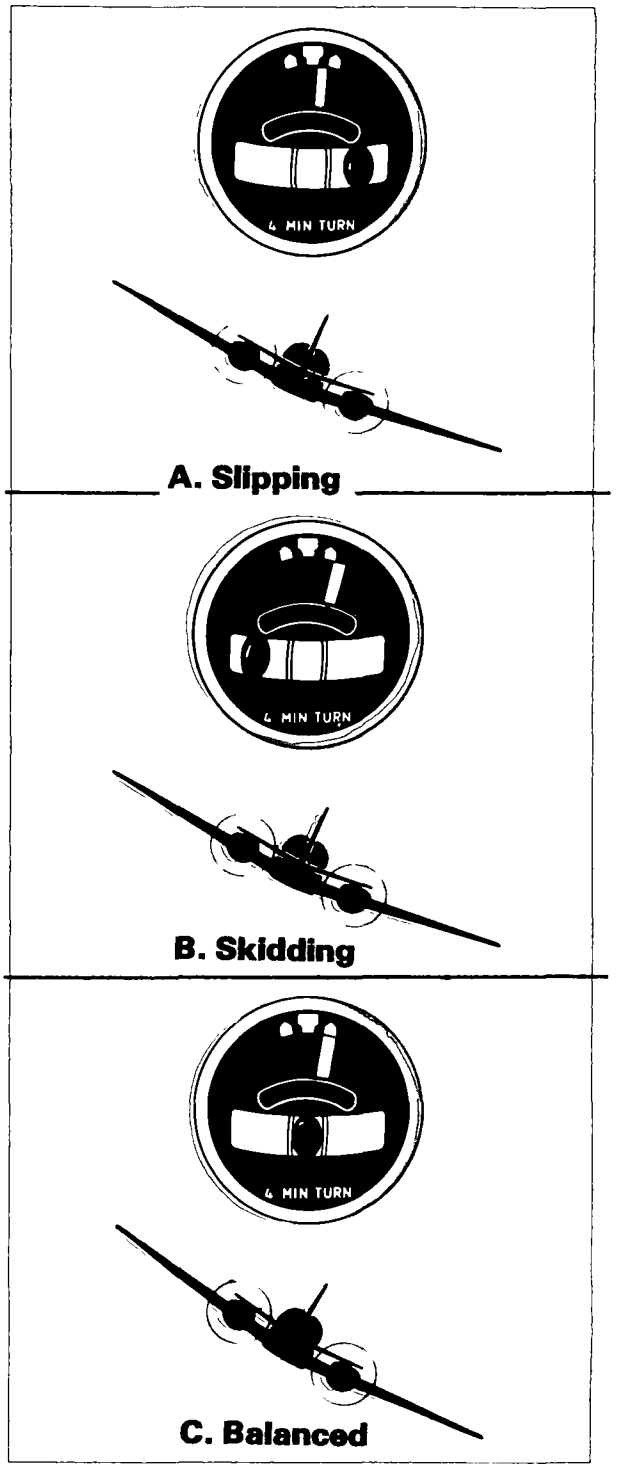


Figure 3-18. Instrument indications of quality control in a turn.

ball is off-center, the aircraft is yawing (slipping or skidding). If the aircraft is slipping, the ball is off-center toward the inside of the turn (low wing) (A, fig 3-18); if skidding, the ball is off-center toward the outside of the turn (high wing) (B, fig 3-18). The ball of the indicator shows the quality of control coordination (C, fig 3-18), whether in turning or straight flight. In fixed wing aircraft, the displacement of the ball to one side of center in wings-level flight indicates the need for an adjustment in rudder trim and possibly aileron trim. In a rotary wing aircraft, the displacement of the ball to one side of center indicates the need for a pedal adjustment. To keep the aircraft from turning, a cyclic movement must be made in the opposite direction.

a. In fixed wing aircraft, an incorrect setting of either aileron or rudder trim, or both, will cause the aircraft to bank and turn. Resetting of the aileron and rudder trim tabs (fig 3-19) will correct the banking tendency.

b. In a fixed wing aircraft, an incorrect setting of the rudder trim results in a tendency to skid gradually out of a straight flightpath. A skid usually causes the aircraft to bank because it increases the velocity and, therefore, the lift of one wing. Accurate trim adjustment facilitates precise bank control.

c. Rudder and aileron trim adjustments in fixed wing aircraft should be made as follows:

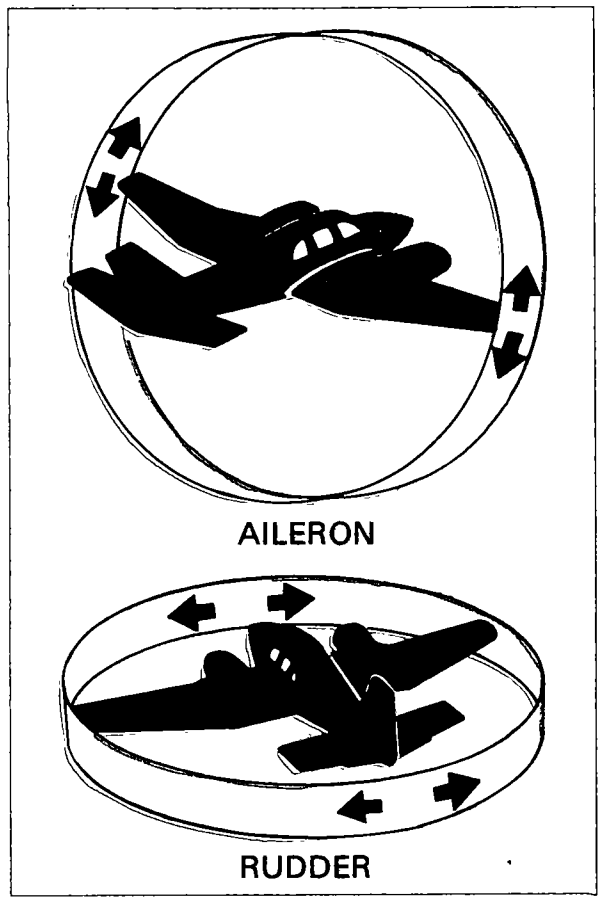


Figure 3-19. Rudder and aileron trim.

(1) Establish balanced flight in the desired attitude with control pressures.

(2) Relieve rudder pressures with rudder trim.

(3) Relieve aileron pressure with aileron trim.

(4) Repeat process until the aircraft will maintain desired attitude.

d. Rotary wing aircraft equipped with trim mechanisms should be trimmed as follows:

(1) Press force trim push button or control centering release button.

(2) Establish level flight with cyclic control with reference to the attitude indicator.

(3) Center the ball of the turn-and-slip indicator with pedals.

(4) Release force trim push button or control centering release button.

(5) Repeat (1) through (4) above, as necessary.

3-24. CROSS-CHECKING OF BANK INSTRUMENTS

All available bank-attitude instruments are used to maintain straight flight and to perform turns. Maintaining straight flight in a balanced condition can be accomplished by using the heading indicator and the attitude indicator. If neither of these instruments is available, the turn needle must be used. For bank control in turns, the attitude indicator is used; if it is not available, the turn needle must be used. In all cases, the turn-and-slip indicator should be included in the cross-check to detect possible malfunctioning of the other bank control instruments and to check for a balanced flight condition.

3-25. [illegible]

Common errors in bank-attitude control are—

a. Failure to cross-check the heading indicator to maintain straight flight.

b. Failure to make corrective action promptly to return to the desired heading.

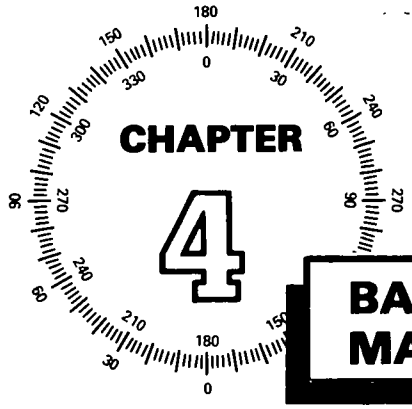
c. Failure to use attitude indicator properly.

d. Failure to control the turn needle properly when using the turn-and-slip indicator.

e. Incorrect pressures being exerted on rudders, ailerons, pedals or cyclic control.

3-26. [illegible]

In instrument flight, instruments must be properly cross-checked and correctly interpreted in order to exert proper control of the aircraft in the desired flightpath and detect any malfunctioning of the instruments. During instrument flight, the instruments provide (1) a reference of the attitude of the aircraft, (2) a reference for the use of power, and (3) an indication of whether the combination of attitude and power is producing the desired performance. Control and trim techniques during instrument flight are identical to those used during visual flight.



CHAPTER 4

BASIC INSTRUMENT MANEUVERS

Section I. FIXED WING

[redacted]

Basic instrument maneuvers are those taught and practiced to obtain proficiency, instrument interpretation, aircraft attitude control, power control, and instrument cross-check.

[redacted]

The method of performing each maneuver is discussed initially under the assumption that all flight instruments are operational (full panel). Then the performance of the maneuver is discussed as if certain instruments are not operational (emergency panel). Except where prohibited by regulation, an emergency panel may be simulated by covering the face of an instrument or by other simulated failure procedures. Refer to chapter 3 for information as to the use of the individual instruments in pitch attitude, bank attitude, and power control.

4-3. INSTRUMENT TAKEOFF

Aviators should be proficient and fully confident in their ability to take off with little or no visual references other than the flight instruments. For an instrument takeoff to be performed, all flight instruments must be operational. The aviator should consult the aircraft operator's manual for the recommended procedures for performing the instrument takeoff. The method outlined in "a" and "b" below is general in nature and may be used where applicable to supplement the instructions set forth in the operator's manual.

a. Aline the aircraft with and on the centerline of the takeoff runway and allow it to roll forward for a short distance to insure that the nosewheel or tailwheel is centered. Hold the brakes firmly and advance the throttles to slightly above idling. Check all flight instruments for correct indications and perform any checklist requirements. After takeoff clearance is received, fully release the brakes and smoothly apply takeoff power. If there are any outside visual references, use them for directional control in the initial part of the takeoff roll. Use brakes only if absolutely necessary for directional control. Any use of brakes will extend the takeoff roll. As the takeoff progresses, the aviator should transition from outside references to the heading indicator and the attitude indicator. Maintain directional control by reference to the heading indicator. Use ailerons only if a bank is indicated on the attitude indicator. As the takeoff roll progresses, bring the airspeed indicator into the cross-check along with the heading indicator and the attitude indicator. When the recommended airspeed is attained, adjust the pitch attitude on the attitude indicator as recommended by the operator's manual. The aircraft should then fly off the ground.

b. After takeoff, maintain directional control with the heading indicator, maintain the recommended pitch attitude and wings level on the attitude indicator, and begin including all other flight instruments in the cross-check. Wait for the altimeter and vertical speed indicator to begin indicating a climb before performing any after-takeoff checklist. Now, if necessary, very carefully adjust the pitch attitude to cause the airspeed to increase at a steady rate toward recommended climbing speed and at the same time insure that the vertical speed indicator shows a steady climb. Control the bank attitude to maintain or correct back to the takeoff heading. Cross-check the turn needle to see if the bank attitude is being indicated correctly on the attitude indicator. As the recommended climb airspeed is attained, reduce power as recommended for climb and adjust pitch attitude as necessary to maintain climbing airspeed.

c. Common errors in instrument takeoffs are—

(1) Improper alinement of the aircraft on the runway.

(2) Failure to use sufficient nosewheel steering and/or rudder to maintain takeoff heading.

(3) Failure to maintain takeoff attitude until a climb is indicated.

(4) Allowing airspeed to go too high before applying takeoff attitude.

(5) Pitch attitude adjustments too large while aircraft is accelerating to climbing airspeed.

[redacted]

a. *Altitude Control.* Cross-check the altimeter to see if the desired altitude is being maintained. If not, correct pitch attitude on the attitude indicator in order to maintain or correct back to the desired altitude. The indications of the vertical speed indicator are used to detect and alert the aviator to possible changes in the desired altitude. If the attitude indicator becomes inoperative, use the vertical speed indicator to assist in maintaining and correcting to the desired altitude.

b. *Heading Control.* Cross-check the heading indicator to see if the desired heading is being maintained. If not, then correct banking attitude on the attitude indicator to maintain or correct back to the desired heading. Check the turn needle to see if the banking attitude is being correctly displayed on the attitude indicator. Use the standby or magnetic compass to see if the heading is being displayed correctly on the heading indicator. If the heading indicator becomes inoperative, use the attitude indicator to maintain or correct back to the desired heading on the magnetic compass. If both the heading and attitude indicators become inoperative, use the turn needle to make straight flight corrections and heading corrections on the magnetic compass. If turns are required to correct the heading, use the procedures contained in paragraph 4-7.

c. *Airspeed Control.* Cross-check the airspeed indicator to see if the desired airspeed is being maintained. If not, adjust the pitch control instruments in order to maintain or correct back to the desired airspeed. Power control will be adjusted as required to maintain a constant altitude. If the airspeed indicator becomes inoperative, use power settings that have previously produced the desired airspeed for any maneuver or configuration.

d. *Power Control.* Use the power normally required or recommended for a maneuver by referring to the power control instruments. If the power application does not produce the desired airspeed, then make a correction using the power control instruments.

e. *Trim.* Changes in power applied, airspeed, configuration, altitude, and loading require trim changes. Maintain the desired aircraft attitude and balanced flight by using trim adjustments as required. See chapter 3 for trim instructions.

f. *Common Errors in Straight-and-Level Flight are—*

(1) Failure to maintain heading.

(2) Using incorrect procedures to correct heading.

(3) Failure to use attitude indicator properly for maintaining altitude.

(4) Not using power control instruments for airspeed adjustments.

(5) Failure to cross-check all instruments in order to detect any instrument malfunction.

(6) Failure to keep aircraft trimmed for balanced flight.

a. *Constant Airspeed, Constant Power Climbs.* To enter a constant airspeed climb using recommended climb power settings, adjust the pitch attitude on the attitude indicator to that which will start the aircraft climbing. Use a pitch attitude that has previously been known to enter the climb smoothly and gradually. There may be a few seconds before the altimeter and vertical speed indicator begin to indicate a climb. Advance power on the power control instruments to the recommended setting. To maintain the desired climbing airspeed, adjust the attitude as required and cross-check the power instruments in order to maintain a constant power setting. Variations in the indication of the vertical speed indicator may be used to alert the aviator to the need for pitch adjustments.

b. *Constant Airspeed, Constant Rate Climbs.* When entering this climb, adjust the pitch attitude as recommended in "a" above. Adjust the power to the settings that have previously been used to perform this maneuver. As the vertical speed indicator approaches the desired rate of climb, adjust the pitch attitude to maintain that rate of climb and adjust the power as necessary to maintain the desired airspeed.

c. *Leveloff From Climbs.* As the aircraft approaches the desired altitude, adjust the pitch attitude on the attitude indicator so that the rate of climb slowly decreases and the altimeter stops on the desired altitude. As a guide, use 10 percent of the indication of the vertical speed indicator to compute the altitude at which to start this pitch attitude adjustment (e.g., when leveling off at 5,000 feet with a rate of climb of 800 feet per minute (fpm), start the pitch attitude adjustment as the altimeter moves past 4,920 feet). Adjust power as required to maintain a desired airspeed or adjust to a computed power setting for cruise operation.

d. *Constant Airspeed, Constant Rate Descent.*

(1) To enter this type descent when a change in airspeed is not desired, adjust the pitch attitude on the attitude indicator. At the same time reduce power as required

to maintain the airspeed. As the vertical speed approaches the desired rate of descent, adjust the pitch attitude as required to maintain this rate.

(2) Two methods are recommended for entering this type descent when a reduction in airspeed is desired. In both methods, once the descent has been stabilized, use pitch attitude adjustments to maintain the desired rate of descent and power to maintain the desired airspeed.

(a) If there is *not* a requirement to leave the altitude immediately, reduce the power to that setting which will normally maintain the desired descending airspeed. Maintain altitude with pitch attitude adjustments until the airspeed approaches the descending airspeed. Then lower the pitch attitude to enter the descent.

(b) If there *is* a requirement to leave the altitude immediately, lower the pitch attitude to enter the descent. At the same time, reduce power to a setting well below that which will normally maintain the airspeed in the descent. This will allow the airspeed to gradually decrease to that desired for the descent.

e. *Leveloff From Descents.* To compute the altitude at which the pitch attitude must be adjusted to stop the descent on the desired altitude, use 10 percent of the rate of descent indicated on the vertical speed indicator (e.g., to level off at 5,000 feet from a descent rate of 500 fpm, the leveloff should be started at 5,050 feet). As the desired altitude is reached, maintain it with pitch attitude control and adjust the power to maintain the desired airspeed.

f. *Heading Control.* Maintain heading control as recommended in paragraph 4-4b.

g. *Trim.* Adjust trim as required to maintain desired aircraft attitude and balanced flight.

h. *Emergency Panel.* If the attitude indicator is not available, maintain level flight and heading control as recommended in paragraph 4-4. During a constant airspeed, constant power climb, use the airspeed indicator to make required pitch attitude adjustments. The trend of the vertical speed indicator also aids in pitch attitude control. During a constant airspeed, constant rate climb or a constant airspeed, constant rate descent, use the vertical speed indicator for pitch attitude adjustments.

i. *Common Errors in Straight Climbs and Descents are—*

(1) Failure to maintain heading.

(2) Failure to coordinate pitch attitude and power adjustments where necessary.

(3) Improper lead when leveling off.

(4) Failure to make pitch attitude adjustments with the attitude indicator.

(5) Failure to adjust pitch attitude and power as altitude or configuration changes.

[redacted]

a. *Entry.* To perform a level turn (fig 4-1), first establish a bank in the direction of turn by coordinated pressure on the ailerons and rudder. Control both pitch attitude and bank attitude by the attitude indicator during the entry. As the banking pointer reaches the desired angle of bank, relax the control pressures or use slight opposite control pressures as may be required to stop and hold the bank. Cross-check the indication of the turn needle to see if it is deflected in the direction of the turn and that the deflection is proportional to the angle of bank being used. Resume cross-checking of all instruments. Loss of vertical lift may require an adjustment of pitch attitude to hold altitude. Any pitch attitude adjustment may require a power change if it is desired that a constant airspeed be maintained.

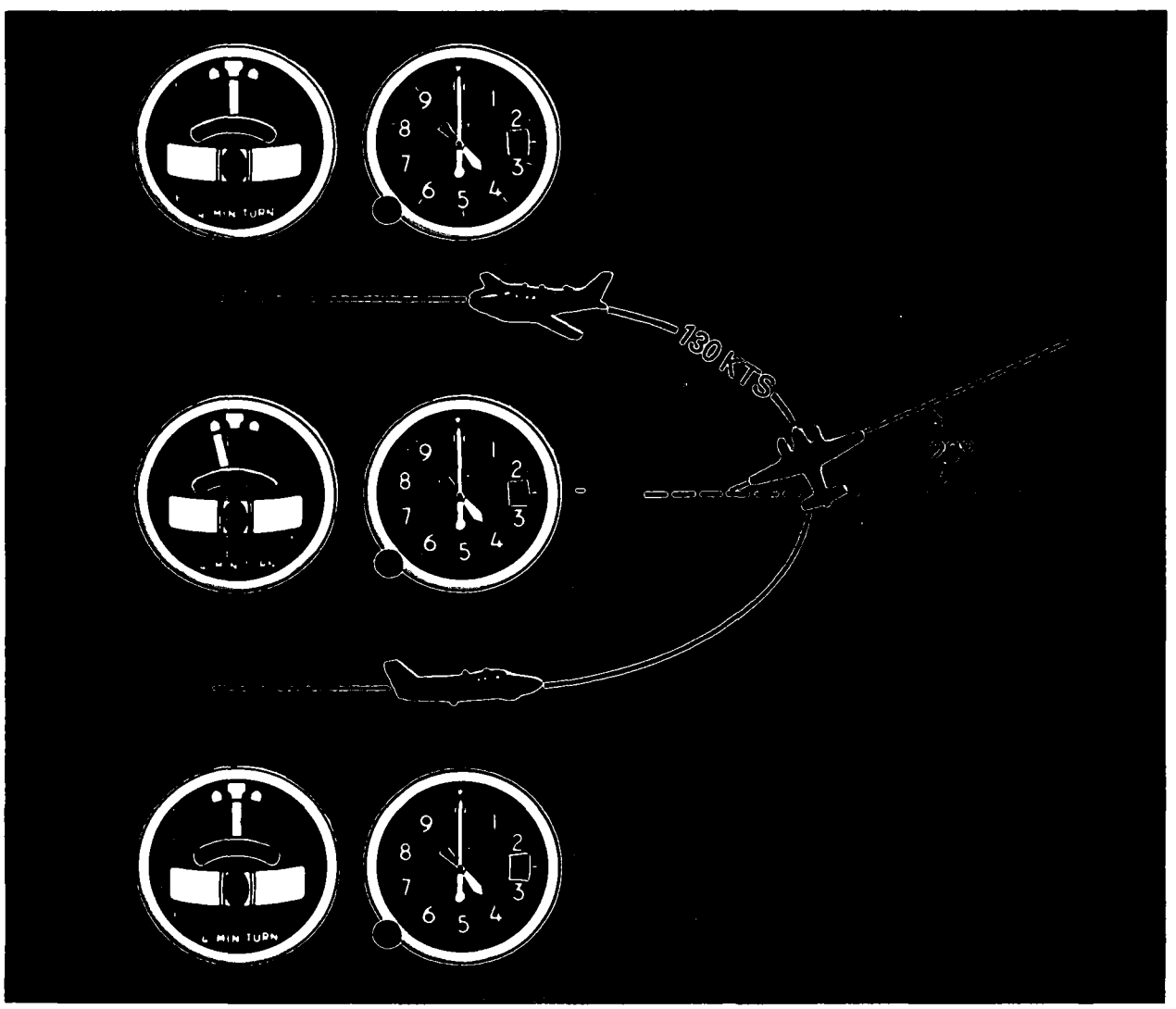


Figure 4-1. Level turns.

b. *Recovery.* To recover to straight-and-level flight, apply coordinated pressure to the ailerons and rudder in the direction opposite to the turn. Control pitch attitude and bank attitude by reference to the attitude indicator. Continue the control pressures so that the banking pointer moves steadily to the zero bank position. Relax control pressures or use slight opposite control pressures as required to stop and hold the heading pointer at zero. Resume cross-checking of all instruments. If the pitch attitude was adjusted during the turn, be prepared at the first indication of a climb on the altimeter or vertical speed indicator to readjust the pitch attitude to maintain altitude. If the power was adjusted during the turn, reset it to the former level flight setting when the airspeed is as desired. After rolling out of a turn, the attitude indicator display may be slightly inaccurate because of precession errors caused by the turn. Until the attitude indicator is operating properly, cross-check the heading and pitch attitude control instruments for any required attitude adjustments.

c. *Trim.* Adjust trim as necessary to maintain the desired attitude and balanced flight.

d. *Emergency Panel.* Without the use of the attitude indicator, control the turn entry, the rate of turn, and the recovery from the turn by reference to the turn needle.

e. *Common Errors in Level Turns are—*

(1) Failure to coordinate aileron and rudder pressures during the entry and recovery.

(2) Losing the correct pitch attitude during entry and recovery.

(3) Failure to stop the bank at the desired angle.

(4) Failure to stop the rollout when the banking pointer returns to zero.

(5) Failure to maintain a constant rate of turn.

[redacted]

a. Entry and recovery control techniques for turns to headings are the same as those for level turns (para 4-6). The angle of bank used should not be more than the number of degrees to be turned, and should not exceed the angle of bank for a standard rate turn (fig 4-2). To roll out of the bank with the heading indicator on the desired heading, the rollout must begin prior to reaching the desired heading. This "lead" or early initiation of the rollout will depend on the angle of bank being used and on the rate of roll used by the aviator. As a guideline, use 1° of lead for every 2° of bank. For example, in a right turn to a heading of 90° and using 28° of bank, the rollout would begin as the heading indicator

passes 76°. To determine if the proper amount of lead was used, check the heading indicator after the wings are level. A variation from the desired heading would indicate the need for a change in lead for future turns.

4-8. STEEP TURNS

a. Any turn greater than standard rate or any turn exceeding 30° bank is considered a *steep* turn. Determine the rate of turn by the attitude indicator or the turn-and-slip indicator. A 4-minute turn needle should indicate a minimum of a 3-needle width deflection, while a 2-minute turn needle should indicate a minimum of a 1½-needle width deflection. This type of turn is seldom necessary or advisable in instrument weather, but it is a good test of the ability of the aviator to react quickly and smoothly to changes in attitude of the aircraft. Regardless of the degree of bank, the techniques of entry and recovery are the same in steep turns as in any other turns. When the bank is steep, however, it is more difficult to control the pitch attitude. This is due to the large variation in the vertical lift components. During the entry to the turn, cross-check the pitch attitude control instruments rapidly so that the pitch attitude may be adjusted upward at the first indication of any altitude loss. After the desired angle of

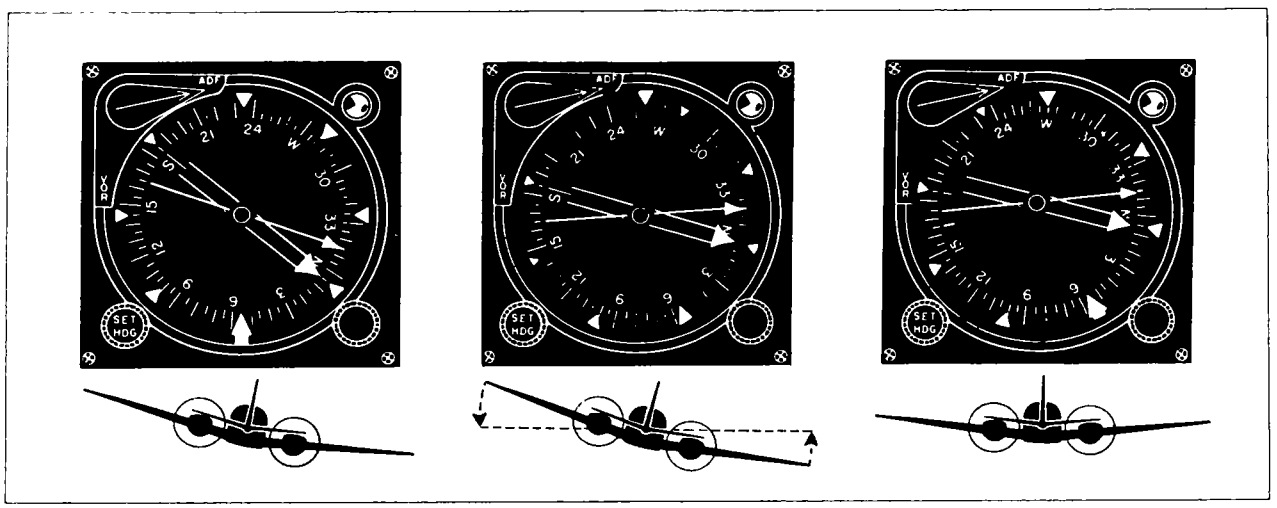


Figure 4-2. Turns to headings using heading indicator.

b. If the attitude indicator is not available, the rollout lead can be determined by using the same number of degrees for rollout as was required to establish the turn on roll-in. If the heading indicator is not available, timed turns (para 4-9) or compass turns (para 4-11) will be required.

c. Common errors in turns to headings are as follows:

(1) Failure to use proper bank for number of degrees to be turned.

(2) Failure to use proper lead in rollout.

(3) Failure to use same rate of roll on roll-in and rollout of the turn.

bank has been established, there may be a requirement to hold aileron and rudder pressures opposite the direction of turn in order to prevent the bank from increasing. The tendency in steep turns for the bank to increase is called the "overbanking tendency." The slight extra speed of the wing on the outside of the turn increases as the bank increases. At the steeper angles of bank, this extra speed will overbalance the lateral stability of the aircraft and cause the bank to continue to increase unless control action is taken to resist it. Increase power as required to maintain the desired airspeed. On the rollout, decrease the pitch attitude as required to maintain altitude and the power as required to maintain airspeed. The use of instruments in the steep turn is the same as in standard rate turns.

b. Errors common in steep turns include—

(1) Failure to maintain altitude.

(2) Failure to maintain proper airspeed.

(3) Improper power and pitch attitude control during entry and recovery.

(4) Improper bank attitude and pitch attitude control.

69. TIMED TURNS

a. In a *timed* turn, the heading of the aircraft is changed a definite number of degrees with reference to the clock and the turn needle. It may be easiest to start the timing when the second hand is at the 3-, 6-, 9-, or 12-o'clock position.

b. Before practicing timed turns, calibrate the turn needle to determine the accuracy of the needle indications. Establish a turn with the needle deflection for a standard rate turn, and note the angle of bank on the attitude indicator. As the second hand passes a convenient point to start the timing, note the heading on the heading indicator. At each 10-second interval, note the heading again. If the heading change is 30° each interval, the turn needle deflection is correct for a standard rate turn (3° per second); if not, change the angle of bank and resulting needle deflection until the turn is standard rate (3° per second). When the turn needle has been calibrated in both directions of turn, note the corrected deflection, if any, and apply it during all timed turns.

c. Timed turns are normally entered from straight-and-level flight. To enter a timed turn, maintain heading until the second hand arrives at the desired position, then start the roll-in.

d. The number of degrees to be turned governs the length of time and rate of turn. Turns of 20° or more are made at standard rate; turns of less than 20°, at half-standard rate. Normally, turns to headings will be in the shortest direction of turn. *For example*, starting a timed turn from heading of north (A, fig 4-3) and turning right to a heading of 120° (B, C, and D, fig

4-3) takes 40 seconds. If the time and the roll-in are started with the second hand in the 12-o'clock position, the rollout will start when the second hand is on the 40-second position (C, fig 4-3). The same rate of rollout is used as was used to roll into the turn. In this way the delay in reaching a standard rate turn indication on roll-in will be canceled by the delay in reaching a wings-level condition on rollout. Upon completion of the rollout, the aircraft should be on the desired heading (D, fig 4-3). When using a half-standard rate turn (1½° per second), it is easier to compute the time by first computing for a standard rate turn (3° per second) and then doubling the time.

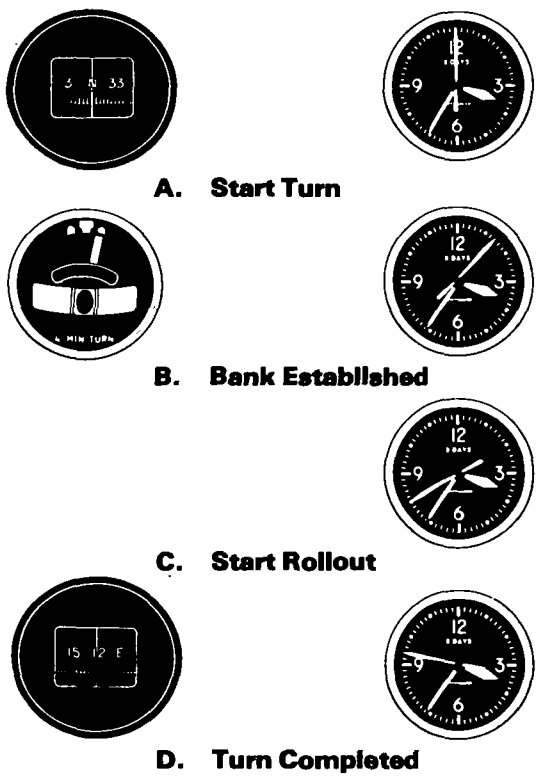


Figure 4-3. Timed turns.

e. Errors common in timed turns include—

(1) Improper direction of turn.

(2) Improper rate of turn.

(3) Failure to enter and recover from timed turns at the same rate.

(4) Failure to compute time correctly for turns.

4-10. CLIMBING AND DESCENDING TURNS

a. To execute climbing and descending turns, combine the technique used in straight climbs and descents with the various turn techniques. For proficiency training, it is recommended that the climbs and descents be made at a definite rate and that the maneuver be checked against time—both in altitude change and in degrees of turn. If the timing is in error, make the leveloff on the desired altitude and roll out of the turn on the desired heading. When entering a turn while performing a rate climb or descent, be prepared to adjust the pitch attitude upward to maintain the desired vertical speed and to add power to maintain the airspeed.

b. Common errors in climbing and descending turns are—

(1) Failure to detect a need for a change in rate of turn or vertical speed.

(2) Overcontrolling power, pitch attitude, or bank attitude.

(3) Those errors associated with turns, timed turns, climbs, and descents.

4-11. COMPASS TURNS (Fig 4-4 and 4-5)

a. The magnetic compass is a basic direction-indicating instrument. It is simple in construction and is highly reliable. If all other direction-indicating instruments fail in flight, the aviator will be forced to use the magnetic compass to determine the aircraft heading. However, the inherent characteristics of the compass must be

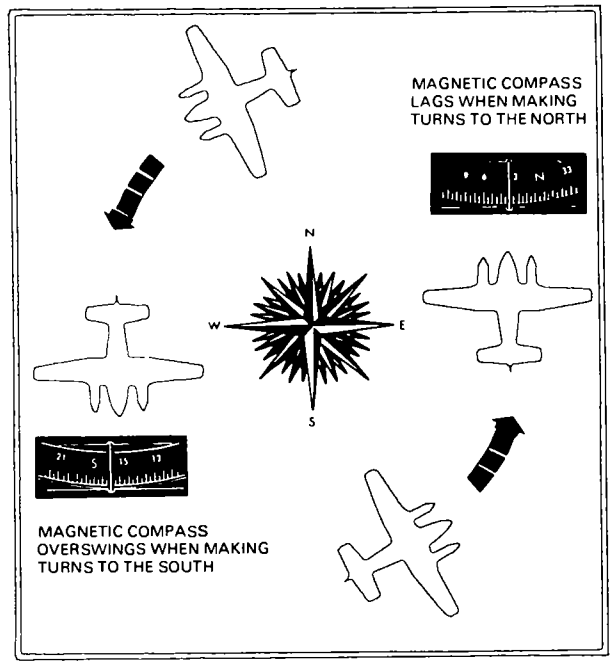


Figure 4-4. Compass turns.

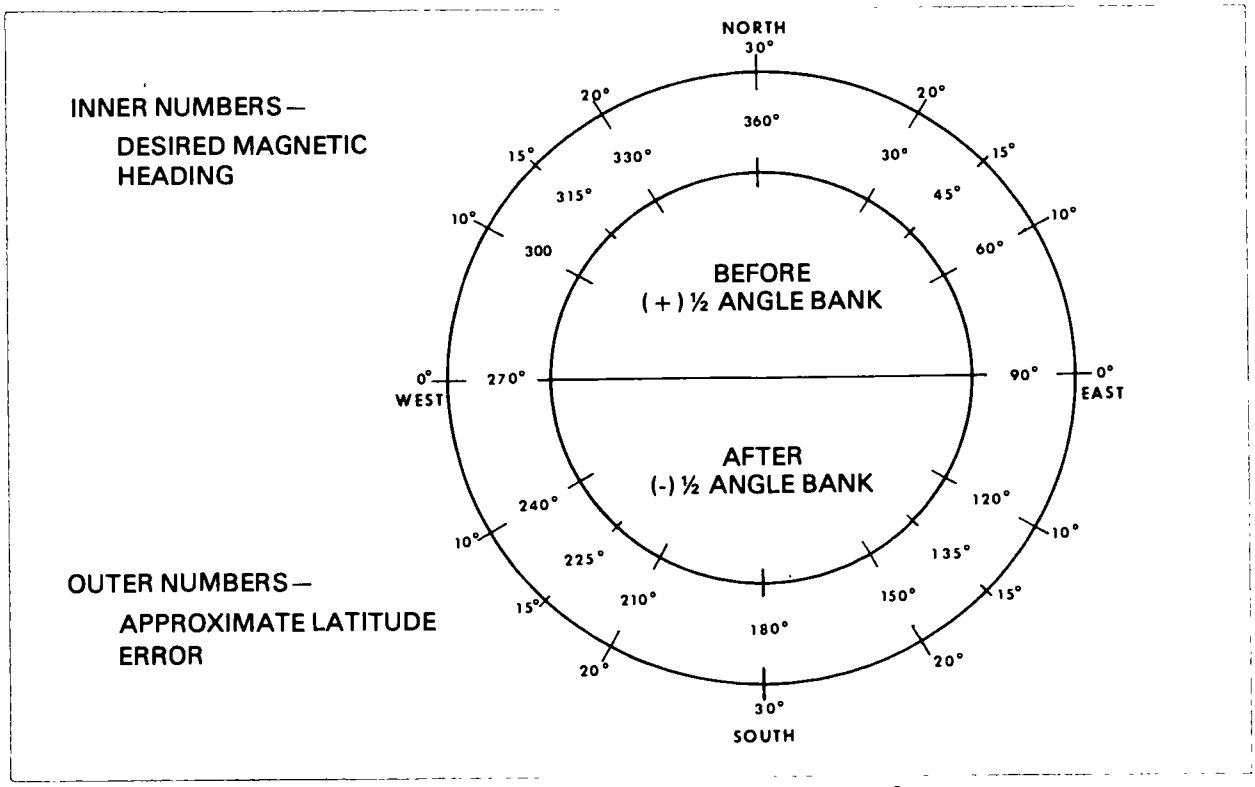


Figure 4-5. Compass turn maneuver procedure.

understood to be able to turn the aircraft to a magnetic heading and maintain it.

b. With an angle of bank between 12° and 18° (and the rate of turn not to exceed a standard rate), the amount of lead or lag to be used when turning to headings of north and south varies with, and is approximately equal to, the latitude of the locality over which the turn is made. This lead or lag is at a minimum over the Equator and increases as the latitude increases, reaching its maximum at the polar regions. The angle of bank must be accurately held to attain success in turns to magnetic compass headings. The compass reading is reliable only when the aircraft is in a wings-level and constant-pitch attitude at a constant airspeed.

c. In the Northern Hemisphere, when turning to a heading of north, the rollout lead must be the number of degrees equal to the latitude plus one-half of the angle of bank used in the turn (fig 4-5). For example, during a left turn to a heading of north in a locality where the latitude is 30° and the angle of bank is 15°, start the rollout when the magnetic compass reads 37.5° (30° plus one-half of 15°). To turn to a heading of south, turn the aircraft past south the number of degrees equal to the latitude minus one-half the angle of bank used in the turn (fig 4-5). For example, when turning to the right to a heading of south, the rollout is started when the magnetic compass reads 202.5° (180° plus 30° minus 7.5°). When turning to a heading of east or west, the usual lead for rollout (one-half the angle of bank) is used. When turning to other than cardinal headings, the lead or lag must be interpolated. South of the Equator, lead and lag are reversed.

d. Errors common in compass turns include—

(1) Failure to level the wings upon completion of turn.

(2) Failure to maintain an angle of bank of 12° to 18°.

(3) Failure to maintain proper attitude.

[redacted]

a. *General.* An unusual attitude is any attitude of the aircraft not required for normal instrument flight. An unusual attitude may result from any one or a combination of several causes. Some of these causes are turbulence, vertigo, confusion, distraction from flight instruments, and failure of flight instruments.

b. *Recognizing Unusual Attitudes.* Normally, an ususual attitude is recognized in one or more of the following—an attitude on the attitude indicator that is not typical of the maneuver being performed or an attitude that is rapidly changing to an extreme position of pitch and/or bank; indications on the heading indicator or turn needle of the aircraft entering a rapid turn from straight flight or increasing its rate of

turn extremely from a normal instrument flight turn; and/or indications of the altimeter, airspeed, and vertical speed changing rapidly from those indications that are normal to the maneuvers being performed. When any of these situations occur, increase the speed of cross-checking to determine quickly if the problem is caused by failure of one or more instruments. Failure of an instrument can be detected by comparing its indications with the other instrument indications. Common failures are those of the attitude indicator (especially if it is the spillable type) and the heading indicator. A quick reference to the turn-and-slip indicator will verify whether or not the turn indications on the attitude indicator or heading indicator are normal for the maneuver being performed. Reference to the other pitch attitude control instruments (airspeed indicator, altimeter, and vertical speed indicator) will verify whether or not the pitch attitude on the attitude indicator is normal for the maneuver being performed. However, if the aviator cannot confirm instrument failure with a quick cross-check, he should promptly apply the procedures for recovery from unusual attitudes.

c. *Recovery From Unusual Attitudes.* (These procedures should be modified or supplemented by any instructions contained in the operator's manual for the aircraft.) When a recovery from an unusual attitude is required, the initial control actions should be made using the power instruments, altimeter, airspeed indicator, vertical speed indicator, and turn-and-slip indicator. The indications of the attitude indicator and heading indicator should be disregarded until it can be ascertained by cross-checking with the other instruments that they are operating properly. The nonspillable attitude indicator may be used when known to be operating correctly. Control movements should be smooth, but applied firmly enough so that the aircraft will promptly move to the desired attitude. Coordinated movement of the control will hasten the recovery and prevent abnormal stress on the aircraft. If the aircraft is in a diving or nose-low pitch attitude, it will be shown by a loss of altitude, an increase in airspeed, and an indication of a descent on the vertical speed indicator. Reduce power in proportion to the indication and trend of movement of the airspeed indicator, center the turn needle and ball with coordinated aileron and rudder pressure, and apply an upward pitch attitude correction until the altimeter and airspeed movements begin to cease. The aircraft is then approaching level flight. When the indications of the altimeter and airspeed indicator begin to reverse their direction of movement, the aircraft is passing through level flight attitude. To remain at or near level flight attitude, some of the pressure to adjust pitch attitude should be released at this time. Incorporate the attitude indicator and heading indicator in the cross-check if they appear to be operating normally. If required by the instructor or if operating under direction of air traffic control (ATC), take action to return to the original heading, altitude, and airspeed. If the aircraft is in a climbing or nose-high pitch attitude as shown by a gain of altitude, a loss of airspeed, and an indication of a climb on the vertical speed indicator, apply power in proportion to the indication and trend of movement of the airspeed indicator. Apply downward pitch attitude correction until the altimeter and airspeed movements begin to cease and center the turn needle and ball. Then as the altimeter and airspeed start to reverse their movement, release some of the control pressure that was required for the pitch attitude adjustment. The remaining procedures are

the same as those performed above after recovering from a descending attitude.

d. *Control Actions.* Remember that the initial recovery actions can be applied simultaneously, but the sequence of actions should not be changed. Prompt power adjustments in a nose-high attitude will aid in preventing a stall or spin, and in a nose-low attitude will aid in preventing excessive buildup of airspeed and loss of altitude. A prompt correction, such as a banking attitude in a dive, will aid in adjusting the pitch attitude and in preventing excessive loss of altitude. Prompt lowering of the pitch attitude in a climbing attitude will aid in preventing a stall or spin. In all cases, prompt, smooth, coordinated control actions should be taken in order to recover from the unusual attitude with a minimum change in altitude and without exceeding the limitations of the airframe or engine.

e. *Spatial Disorientation.* After recovery from an unusual attitude, the aviator may suffer from vertigo or spatial disorientation for some time. Instrument cross-check must be continuous and an attempt be made to relax any unneeded pressures on the controls. This gives the aircraft an opportunity to resume balanced or coordinated flight. An uncoordinated flight condition will frequently induce or prolong spatial disorientation. Relaxing the control pressures will aid in preventing the application of unneeded control pressures that may be induced by spatial disorientation.

f. *Spins.* If an unusual attitude results in a spin, apply recovery procedures as outlined in the operator's manual for the aircraft. A spin is indicated on the flight instruments in the following manner:

(1) Turn needle displaced fully in the direction of spin, with the ball usually displaced fully in the direction opposite to the turn needle. However, occasionally the ball will oscillate back and forth across the center of the tube.

(2) The needle of the airspeed indicator will be hovering at the stall airspeed.

(3) The vertical speed indicator will indicate a high rate of descent.

(4) The altimeter will indicate a rapid loss of altitude.

(5) The indications of the attitude indicator and heading indicator should be disregarded as they will probably be erroneous or too difficult to use for a recovery. After spin recovery procedures are applied, closely check the turn needle for a sudden movement back toward center. This indicates that the rotation of the aircraft has been stopped. Promptly center the rudder pedals so that the aircraft will not begin rotation in the opposite direction. Complete the recovery by using the procedure for recovery from a dive. Make pitch adjustments carefully while the airspeed is still low. Refer to the turn-and-slip indicator to insure that the wings remain level.

g. *Common errors in recovery from unusual attitudes are—*

(1) Failure to adjust power adequately.

(2) Executing procedures in incorrect sequence.

(3) Failure to recognize level flight pitch attitude.

(4) Allowing excessive altitude variation during recovery.

(5) Failure to maintain required heading, altitude, or airspeed after recovery.

Section II. ROTARY WING

[redacted]

Since the advent of helicopter flight, field commanders have desired the use of helicopters in both good and adverse weather conditions in order to gain tactical advantage and the element of surprise through increased mobility.

a. The basic principle of helicopter instrument flight under any and all weather conditions stems from the application of fundamentals for visual flight rules (VFR) helicopter flight. There are only two elements of control in all aircraft—the attitude of the aircraft to the horizon and the power applied. Therefore, all maneuvers must be based solidly upon attitude and power control references. Airspeed is a result of attitude control; altitude is a result of power control. To properly change to or hold any desired altitude, the aviator must have a tentative estimate of basic power settings for climb, cruise, and descent.

b. The maneuvers discussed in this section are designed to develop proficiency in the attitude control of rotary wing aircraft and can be considered as the first step in fulfilling the requirement of all-weather operations.

c. The method of performing each maneuver presupposes full panel and emergency panel, with the exception of the instrument takeoff. Perform the instrument takeoff with full panel. Except where prohibited by directives, emergency panel is simulated by covering one or more of the flight instruments or by deactivating certain flight instruments.

d. Airspeeds and power settings will be as recommended in the operator's manual for the aircraft.

[redacted]

The following procedures for making an instrument takeoff will be modified or changed as necessary to conform with any procedures set forth in the operator's manual for the aircraft.

a. Adjust the attitude indicator by setting the miniature aircraft as appropriate for the aircraft being flown. After the aircraft is alined with the runway or takeoff pad, to prevent forward movement of helicopters equipped with wheel-type landing gear, set the parking brakes or apply the toe brakes. If the parking brake is used, it must be unlocked after the takeoff has been completed. Apply sufficient friction to the collective pitch control to minimize overcontrolling and to prevent collective pitch creeping. However, in order not to limit pitch control movement, the application of excessive friction should be avoided.

b. After a recheck of all instruments to see if they are operating properly, start the takeoff (fig 4-6) by applying collective pitch and a predetermined power setting (more than is necessary for hovering, but not exceeding maximum allowable power—depending on the aircraft being flown). Add power smoothly and steadily to gain airspeed and altitude simultaneously and to prevent settling to the ground. As power is applied and the helicopter becomes airborne, pedals are used initially to maintain the desired heading. At the same time apply forward cyclic control to start the acceleration to climbing airspeed. In the initial acceleration, the attitude of the

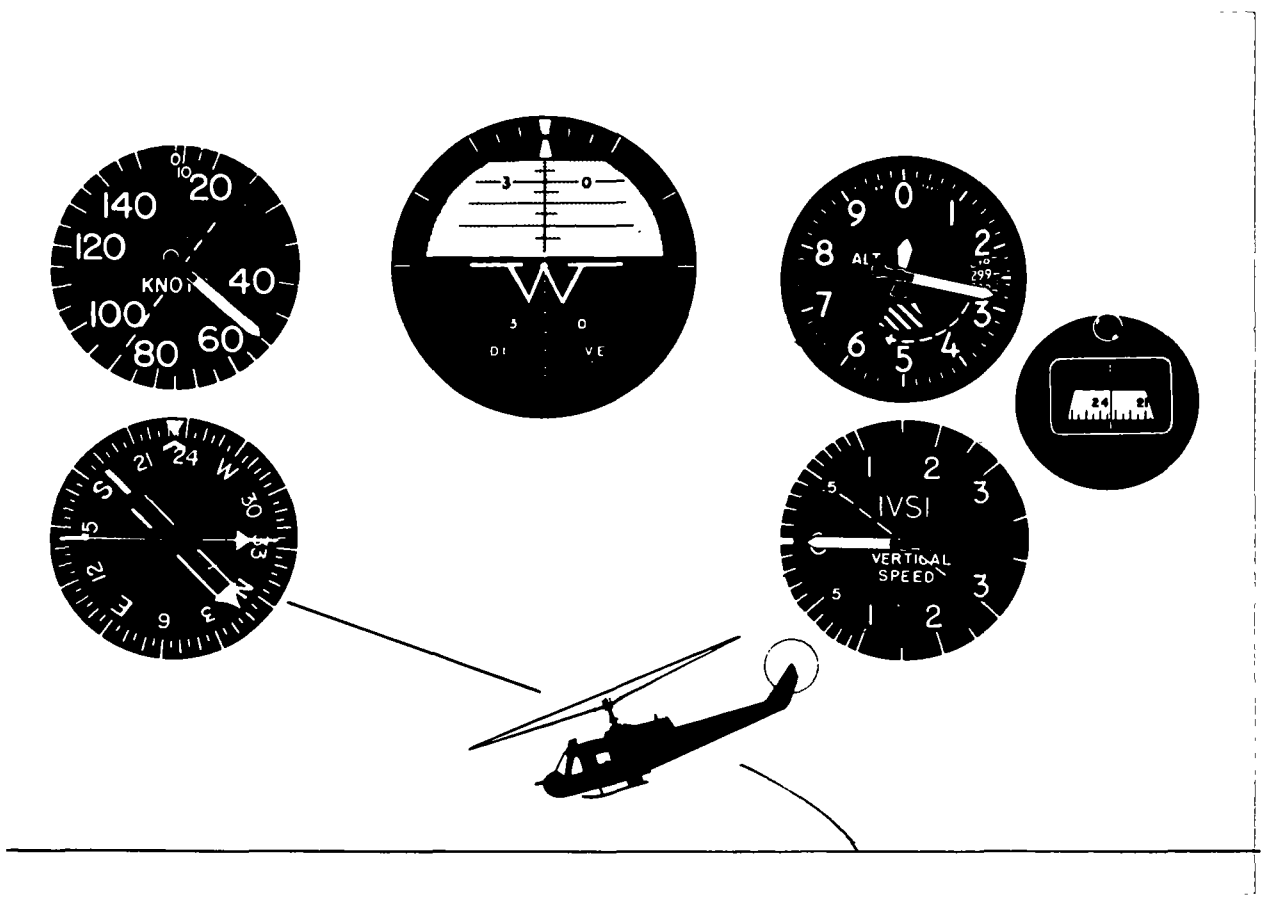


Figure 4-6. Flight instruments during the takeoff.

aircraft as read from the attitude indicator should be one to two bar widths below the horizon. As airspeed increases to the appropriate climb airspeed, adjust the nose of the aircraft gradually to the climb attitude. As climbing airspeed is reached, reduce power to the climbing power setting and transition to fully coordinated flight.

c. During the initial climbout, minor corrections to heading should be made with *pedals only* until sufficient airspeed is attained to transition to coordinated flight. A rapid cross-check must be started at the same time the aircraft leaves the ground and should include all available instruments.

d. Errors common in the instrument takeoff include—

(1) Failure to maintain heading.

(2) Overcontrolling pedals.

(3) Failure to use required power.

(4) Failure to adjust pitch attitude as climbing airspeed is reached.

(5) Failure to cross-check all available instruments.

(6) Overcontrolling pitch attitude.

[redacted]

a. The straight climb (fig 4-7) can be entered from normal cruise.

b. To enter a climb from normal cruise, increase power to the setting which will produce a 500-feet-per-minute (fpm) rate of climb. As power is increased, a correction for trim is made with pedals. If cruise and climb airspeeds are the same, there will be no apparent change of attitude, as read from the attitude indicator. If the amount of power applied does not produce the desired rate, make minor adjustments. As a rule of thumb, a change of 1 torque pound will change the rate of climb 100 fpm.

c. During climb, the heading, attitude, and airspeed are maintained with cyclic control. Rate of climb is controlled with power. Trim is maintained with pedals. Although the amount of lead varies with the aircraft and individual technique, a lead of approximately 40 feet should be used to level off at a desired altitude.

d. To level off at normal cruise, the cyclic is adjusted to establish the desired attitude with reference to the attitude indicator. Power is adjusted to maintain normal cruise airspeed.

e. Errors common in straight climbs include—

(1) Improper use of power.

(2) Overcontrolling pitch attitude.

(3) Failure to maintain heading.

(4) Failure to level off at the desired altitude.

(5) Failure to maintain adequate cross-check.

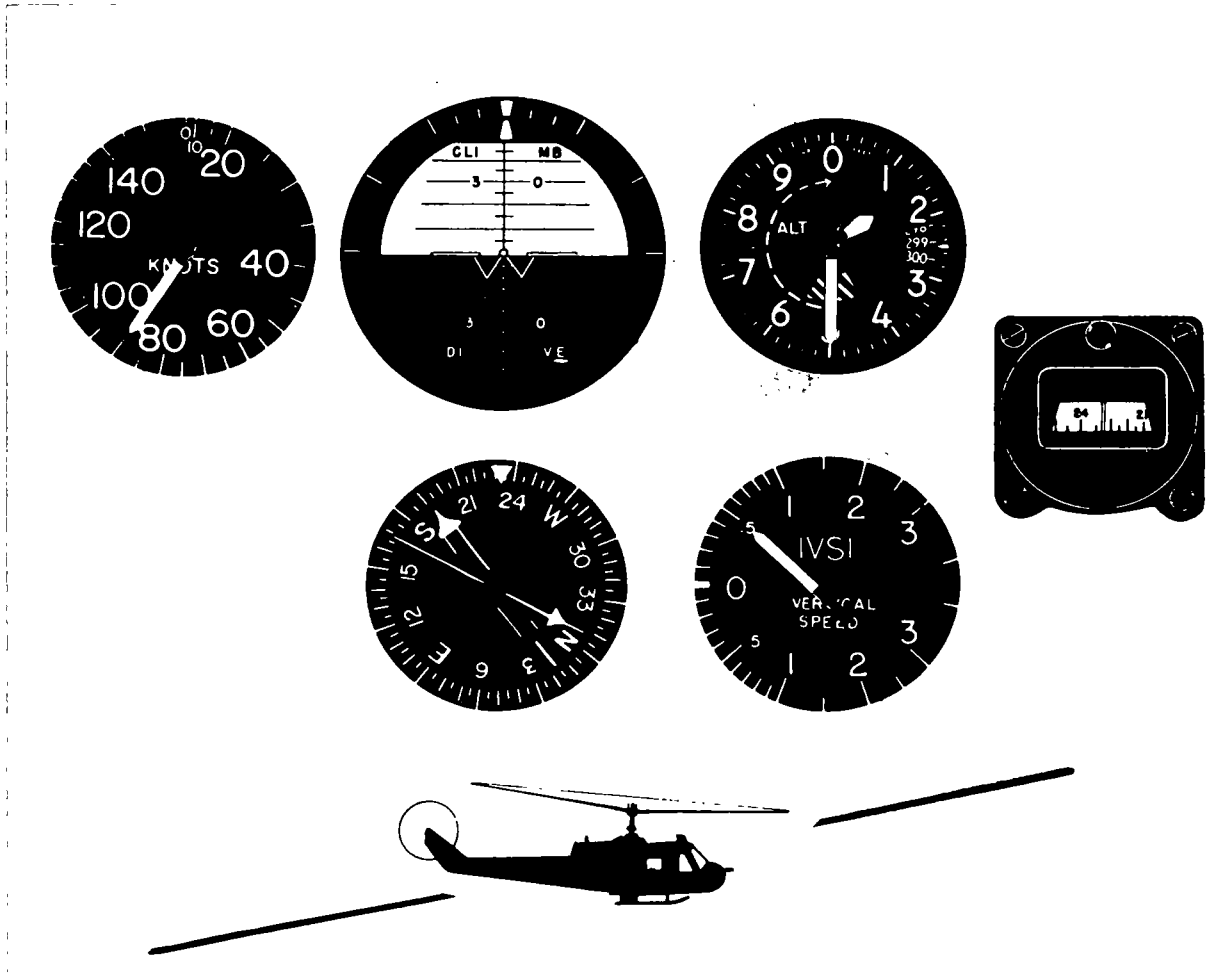


Figure 4-7. Straight climb.

4-16. STRAIGHT-AND-LEVEL FLIGHT

a. Exact straight-and-level flight is possible only under ideal conditions, which rarely exist. Turbulence may cause changes in the helicopter's attitude, altitude, and heading. In every flight attitude, the forces acting on the helicopter have a definite relationship. These forces (lift, weight, drag, and thrust) must be in balance for straight-and-level, unaccelerated flight. When an instrument indicates a need for an adjustment to maintain a given performance, other instruments will reflect the amount and direction in which the adjustment should be made. For example, if the airspeed indicator shows a decrease in airspeed, the torque pressure and/or altimeter will indicate the adjustment to be made in power and/or altitude. When altitude, airspeed, and level flight are being maintained, the miniature airplane of the attitude indicator should be adjusted to reflect the level flight attitude; thereafter, any deviation in attitude can be read directly from the attitude indicator (fig 4-8). Since the miniature aircraft is set for level flight at normal cruise, it will be seen as an approximate one-bar above-the-horizon indication when the aircraft is in level flight at slow cruise. Make corrections for attitude when any deviation is observed.

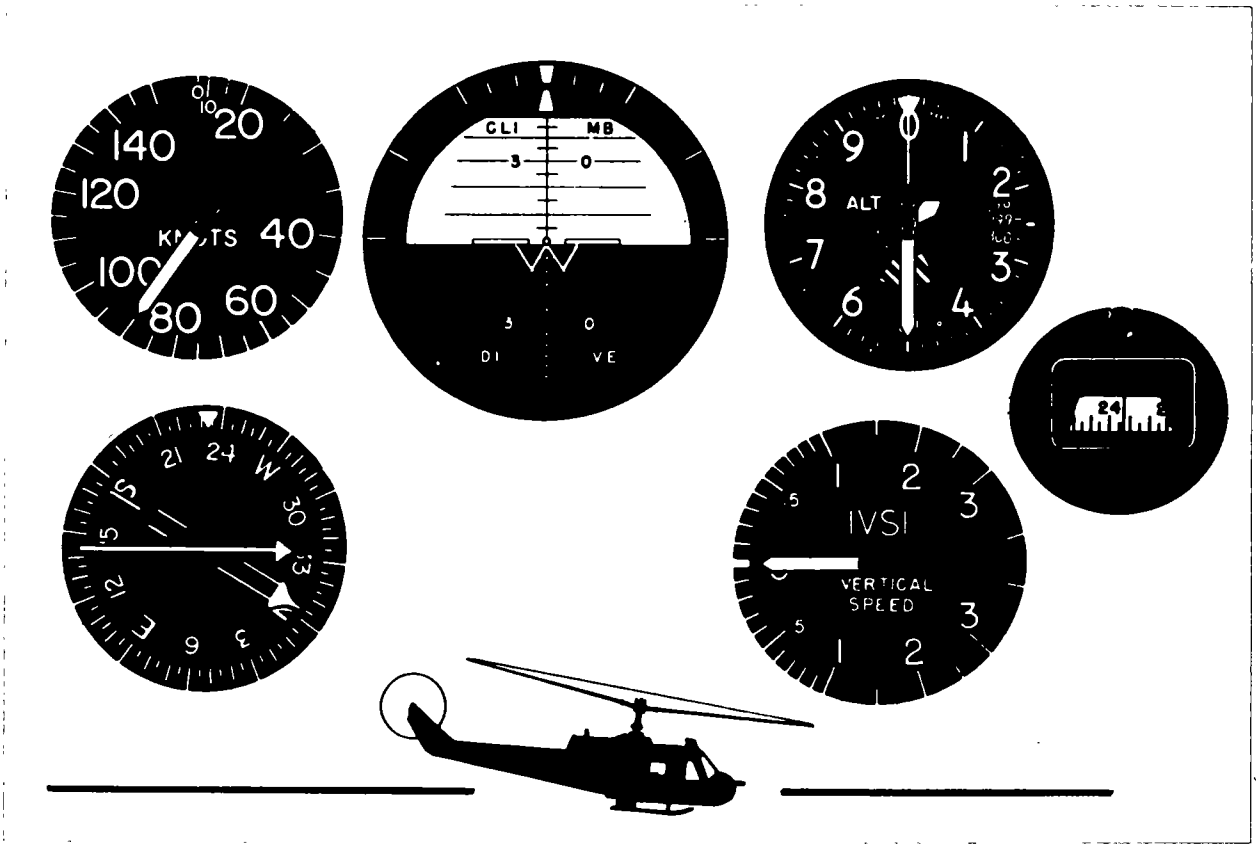


Figure 4-8. Straight-and-level flight.

b. Any deviation from the desired heading will be shown on the heading indicator. Immediate and smooth application of cyclic control is initiated to return the aircraft to the desired heading. The sooner a need for a correction is observed, the smaller the amount of correction needed. For deviations of 20° or more, use a standard rate turn. For deviations of less than 20°, a half-standard rate turn is sufficient. Any time an instrument indicates a change in attitude, correction should be made. Then, instead of watching that particular instrument to see the effects of the adjustment, the cross-check is continued before finally returning to the original instrument. In this way, the entire panel will reflect the total effect of the adjustment. A helicopter does not remain in any given attitude; therefore, by the time a cross-check has been completed and the necessary adjustments have been made, another cross-check must be initiated.

c. During straight-and-level flight, heading and altitude are maintained with cyclic control; airspeed with power; trim with pedals. Power is used to adjust minor variations of altitude only if the desired altitude cannot be maintained by varying pitch attitude without exceeding ± 10 knots airspeed.

d. Errors common in straight-and-level flight include—

(1) Failure to maintain heading.

(2) Failure to maintain altitude.

(3) Failure to cross-check all available instruments.

(4) Overcontrolling power and pitch attitude.

[redacted]

a. Straight descents can be entered from either normal or slow cruise. To enter a descent (fig 4-9), reduce power to the setting which results in the desired rate of descent. To maintain trim as the power is reduced, a correction for torque is made with pedals. If the initial power reduction does not produce the desired rate of descent, additional adjustment is made using the rule of thumb described in paragraph 4-15b.

b. During descent, the heading, attitude, and airspeed are maintained with cyclic control. Rate of descent is controlled with power. Trim is maintained with pedals. To level off from the descent, power is applied prior to reaching the desired altitude. This will check the downward movement in sufficient time to prevent going below the desired altitude. The amount of lead depends on the weight of the aircraft and the rate of descent. For a 500-fpm rate of descent, the lead is normally ten percent of the rate of descent.

c. When the proper altitude for starting the leveloff is reached, power is applied to the predetermined power setting and the vertical speed is checked to determine if

level flight has been established. The altimeter and airspeed indicator should also be checked at this time to insure flight is at the proper airspeed and altitude.

d. Errors common in straight descents include—

(1) Failure to maintain heading.

(2) Failure to establish desired rate of descent.

(3) Failure to maintain proper trim.

(4) Failure to level off at desired altitude.

(5) Overcontrolling pitch attitude.

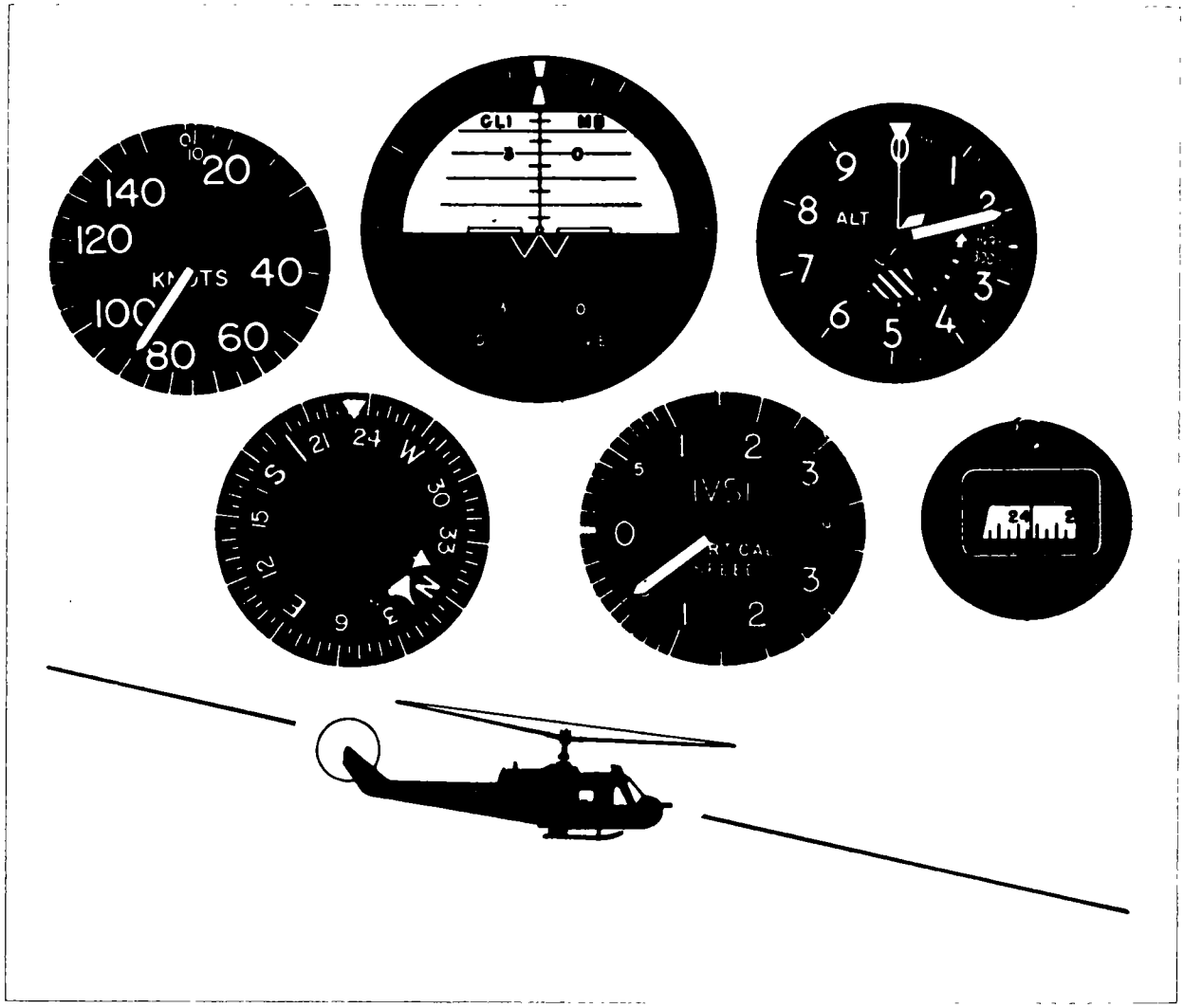


Figure 4-9. Straight descent.

4-18. TURNS

Determine the angle of bank necessary to produce a standard rate turn by the true airspeed of the aircraft. At an airspeed of 70 to 90 knots, the angle of bank of the standard rate turn is approximately 12° to 15°, as read from the attitude indicator. The number of degrees to be turned governs the amount of bank to be used. A change in heading of 20° or more requires a standard rate turn (3° per second) and is shown as a 2-needle deflection on the 4-minute turn-and-slip indicator. For changes of less than 20°, one-half standard rate is sufficient, and is shown as a 1-needle deflection.

4-19. LEVEL TURNS

a. To enter a turn, a movement of the cyclic control is applied in the direction of the desired turn (fig 4-10). The roll-in should be smooth and steady and should take approximately 4 to 6 seconds. The initial bank is started with reference to the attitude indicator. When the desired angle of bank and rate of turn have been attained, control pressure should be relaxed to prevent overbanking. To recover to straight-and-level flight, coordinated movement of the cyclic control is applied in a direction opposite to the established turn. The rate of rollout should be the same as the rate of roll-in. Straight-and-level flight

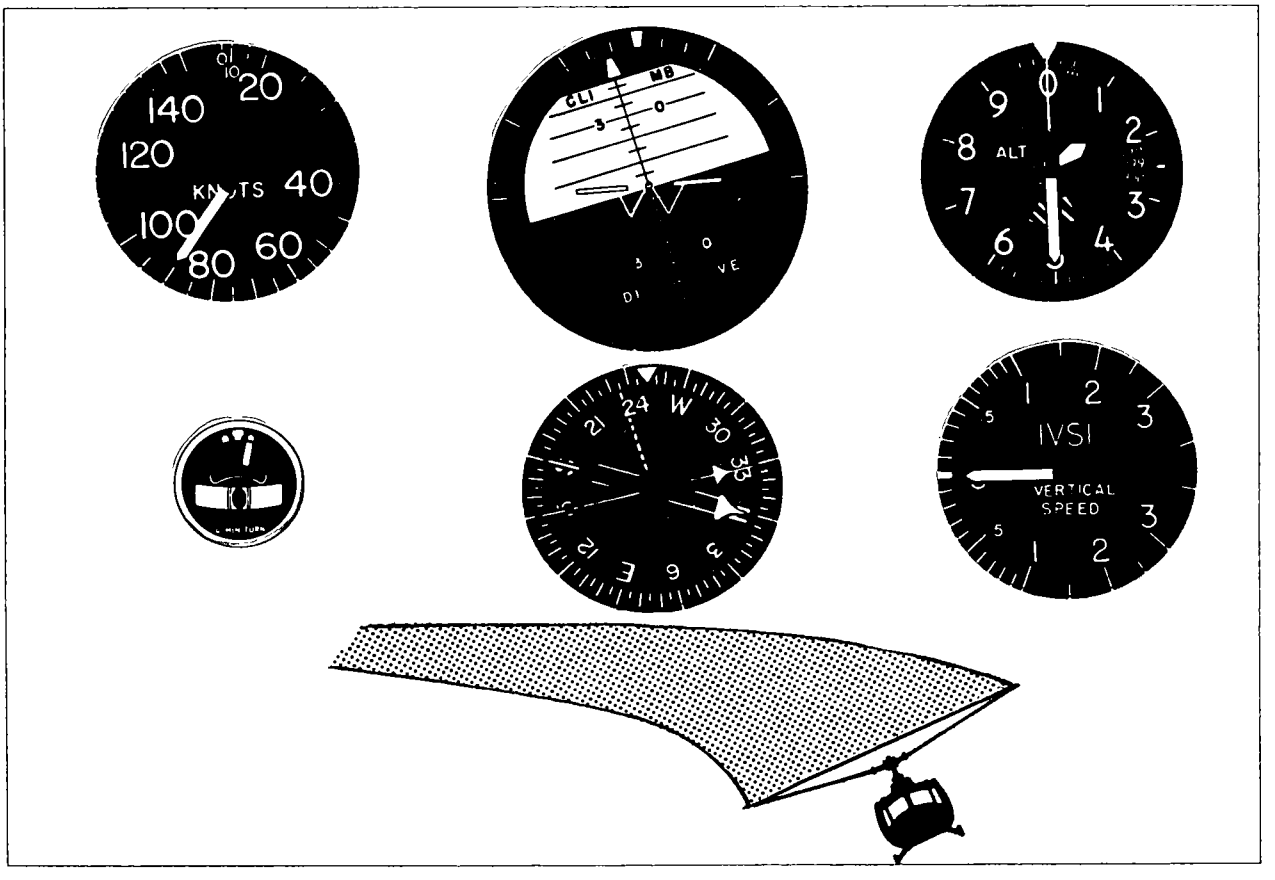


Figure 4-10. Level turns.

should be established with reference to all available instruments.

b. Errors common in level turns include—

(1) Failure to maintain constant rate of turn.

(2) Failure to maintain altitude.

(3) Failure to maintain airspeed.

(4) Varying rate of roll-in and rollout.

[redacted]

a. A turn to a heading (fig 4-11) consists of a level turn to a specific heading as read from the heading indicator, and is performed at normal cruise. Turns to specified headings should be made in the shortest direction. The turn is entered and maintained as described in the level turn maneuver. Since the aircraft will continue to turn as long as the bank is held, the rollout must be started before reaching the desired heading. The amount of lead used to roll out on a desired heading should be equal to one-half the angle of bank. The rollout on a heading is performed in the same manner as the rollout of the level turn. When the heading for starting the rollout is reached, cyclic control is applied in the direction opposite the turn.

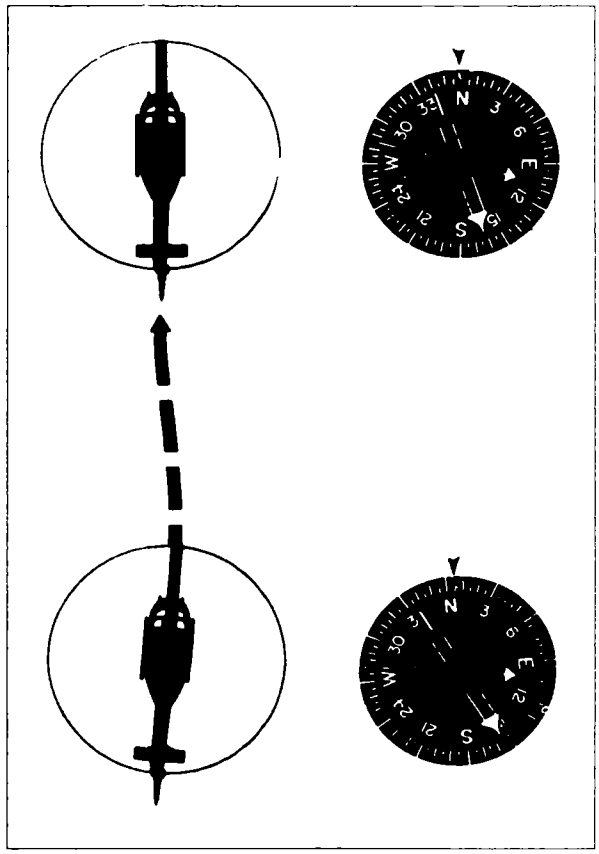


Figure 4-11. Turns to headings.

b. Errors common in turns to headings include—

(1) Failure to use proper lead in rollout of the turn.

(2) Failure to maintain altitude.

(3) Failure to recover from the turn with the proper heading and altitude.

(4) Overcontrolling pitch and bank attitudes.

4-21. COMPASS TURNS

Refer to paragraph 4-11 for the procedure for making compass turns.

4-22. STEEP TURNS

a. Any turn greater than standard rate is considered a steep turn; however, for practice, a 4-minute turn needle should indicate a 3- to 3½-needle width turn. A steep turn is seldom necessary or advisable in instrument weather, but it is a good test of the individual's ability to react quickly and smoothly to changes in aircraft attitude. The techniques of entry and recovery are the same as for any turn maneuver. Rate of turn and attitude are maintained with cyclic control; airspeed and altitude are maintained with power.

b. Errors common in steep turns include—

(1) Failure to maintain altitude.

(2) Failure to hold a constant rate of turn.

(3) Failure to maintain airspeed.

4-23. TIMED TURNS

a. In a timed turn, the heading of the aircraft is changed a definite number of degrees with reference to the turn-and-slip indicator and the clock. For practice, the timed turn is performed at normal cruise with the heading and attitude indicators covered. To perform accurate timed turns, the needle of the turn-and-slip indicator must be calibrated in both left and right turns.

b. To calibrate the turn needle, the approximate angle of bank for a standard rate turn is established with reference to the attitude indicator. Necessary changes are made to produce an indication of a standard rate turn with reference to the turn needle. Unless oscillations of the turn needle are of equal distance on either side of the standard rate position (averaged out), errors will result in the rate of turn. After establishing the rate of turn, the position of the second hand of the clock and the heading are noted. The rate of turn is maintained until a predetermined time has elapsed—and the heading is noted again.

c. Exact timing is very important. If the turn needle is in calibration, a standard rate of turn for 10 seconds will produce a change in heading of 30°. Any deviation is corrected by changing the position of the turn needle so that a turn of 3° per second results. When the needle is properly calibrated, the position is carefully noted and used during all standard rate turns.

d. Prior to starting the turn, the time necessary to turn to the new magnetic heading must be computed. To compute the time in seconds, the angular difference (shortest direction) between the present heading and the new heading is divided by three.

e. The techniques of entry and control of the timed turn are the same as for the level turn (para 4-19). The position of the second hand of the clock must be noted when the turn is started (fig 4-12). For ease in timing, it is best to start the time when the second hand passes the 3-, 6-, 9-, or 12-o'clock position. The standard rate of turn must be maintained until the predetermined time has elapsed, then the rollout is started. The rate of rollout is the same as the rate of roll-in. After straight-and-level flight is established, the compass should indicate the desired heading.

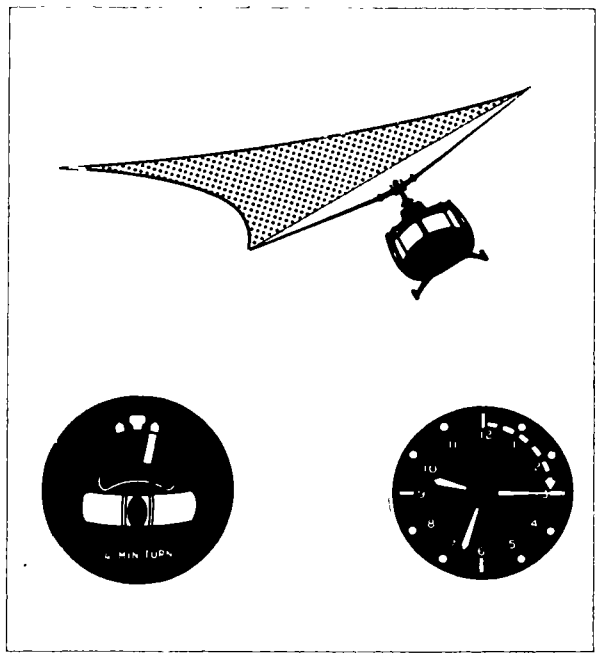


Figure 4-12. Timed turns.

f. Errors common in timed turns include—

(1) Failure to maintain a standard rate turn.

(2) Failure to correctly compute the time to complete the turn.

(3) Failure to use the same rate of roll-in and rollout of the turn.

(4) Failure to maintain altitude.

4-24. CLIMBING TURNS

a. A climbing turn (fig 4-13) is a combination of a climb and a turn as discussed previously in paragraphs 4-15, 4-18, 4-20, and 4-21. For practice, a climbing turn consists of a climb of 500 feet and a turn of 180° in 60 seconds. In this maneuver, the rate of climb and the rate of turn are both checked against time. The climbing turn is generally performed at normal cruise and requires a very rapid cross-check for precise execution.

b. The climbing turn (fig 4-13) is started as the second hand of the clock passes the 3-, 6-, 9-, or 12-o'clock position. As the power is applied to the predetermined setting, torque corrections should be made with pedals to maintain trim. The initial bank should be established with reference to the attitude indicator. To maintain the rate of turn, minor bank

corrections are made with reference to the turn-and-slip indicator. During the climbing turn, the rate of turn and airspeed are maintained with cyclic control; the rate of climb, with power; and trim, with pedals. Power is used to adjust the rate of climb if deviation from desired airspeed is ± 5 knots. (The ± 5 knots is used for minor pitch correction during climbs and descents.) After 30 seconds, the aircraft will have turned approximately 90° and climbed approximately 250 feet. If the instruments indicate other than the desired readings, the rate of climb and/or turn should be adjusted as necessary. A further check can be made at the expiration of 45 seconds. Adjustments in the rate of climb and/or turn should again be made if necessary. Normally, the recovery should be started as the second hand reaches the original starting position (60 seconds). However, regardless of the time factor, a recovery should be made when the desired heading and altitude have been reached.

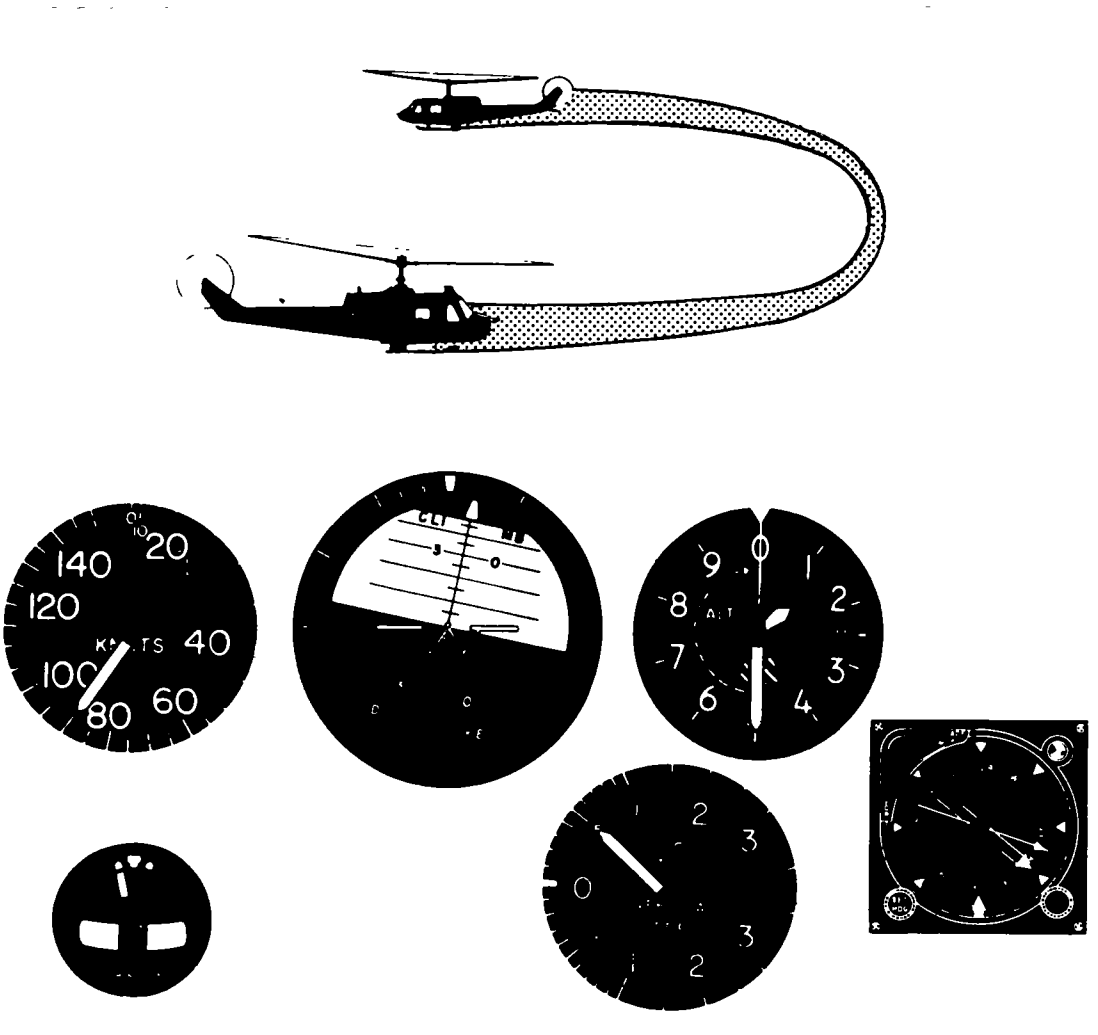


Figure 4-13. Climbing turns.

c. Errors common in climbing turns include—

(1) Failure to detect a need for a change in rate of turn and/or climb.

(2) Improper use of power.

(3) Improper use of pedals.

4-25. DESCENDING TURNS

a. A descending turn (fig 4-14) is a combination of a descent and a turn as discussed previously in paragraphs 4-17, 4-18, 4-20, and 4-21. For practice, a descending turn consists of a descent of 500 feet and a turn of 180° in 60 seconds. In this maneuver, the rate of descent and the rate of turn are both checked against time.

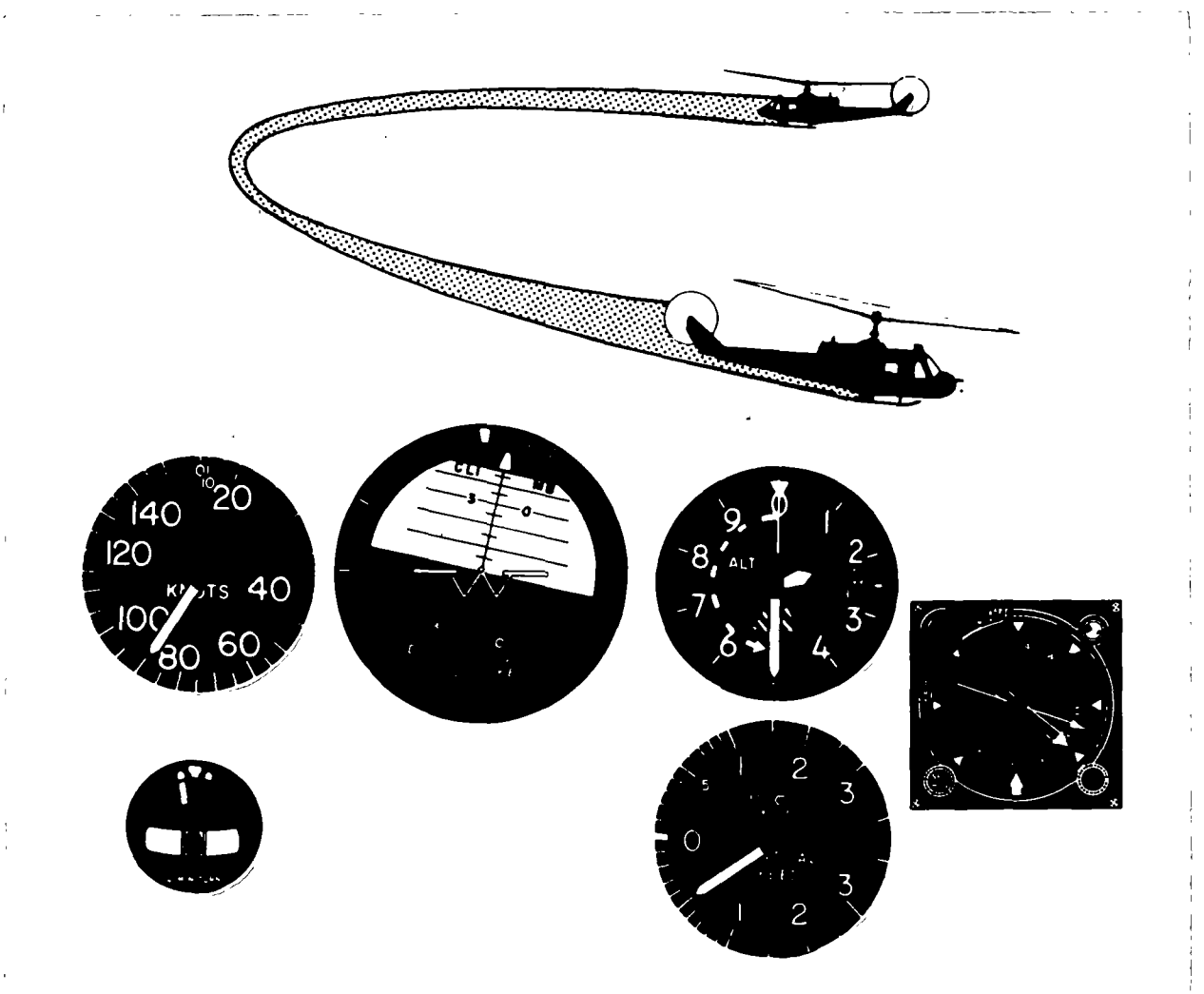


Figure 4-14. Descending turns.

The descending turn is generally performed at normal cruise airspeed and requires a very rapid cross-check for precise execution.

b. The descending turn is started as the second hand of the clock passes the 3-, 6-, 9-, or 12-o'clock position. As the power is reduced to the predetermined setting, torque correction should be made with the pedals to maintain trim. The initial bank should be established with reference to the attitude indicator. To maintain the rate of turn, minor bank corrections are made with reference to the turn-and-slip indicator. During the descending turn, the rate of turn and airspeed are maintained with cyclic control; rate of descent, with power; and trim, with pedals. Power is used to adjust the rate of descent only if the desired airspeed is exceeded by $\pm$ 5 knots. (The $\pm$ 5 knots is used for minor pitch correction during climbs and descents.) After 30 seconds, the aircraft will have turned approximately 90° and descended approximately 250 feet. If the instruments indicate other than the desired readings, the rate of descent and/or turn should be adjusted as necessary. A further check can be made at the expiration of 45 seconds. Adjustments in the rate of descent and/or turn should again be made if necessary. Normally, the recovery should be started as the second hand reaches the original starting position (60 seconds). However, regardless of the time factor, a recovery should be made when the desired heading and altitude have been reached.

c. Errors common in descending turns include—

(1) Failure to detect a need for a change in rate of turn or rate of descent.

(2) Improper use of power.

(3) Improper use of pedals.

(4) Failure to recover from the turn with the proper heading and altitude.

(5) Overcontrolling pitch and bank attitudes.

4-26. UNUSUAL ATTITUDES AND RECOVERIES

a. Any maneuver not required for normal instrument flight is an unusual attitude and may be caused by turbulence, vertigo, instrument failure, or carelessness in cross-checking. Due to the inherent instability of the helicopter, unusual attitudes can be extremely critical. As soon as an unusual attitude is detected, make a recovery to level flight as quickly as possible with a minimum loss of altitude.

b. The recovery from an unusual attitude requires an immediate analysis of what the helicopter is doing and how to return it to normal flight as quickly as possible with a minimum loss of altitude.

c. To recover from an unusual attitude, correct bank and pitch and adjust power as necessary. All components are changed almost simultaneously with little lead of one over the other; e.g., if the aircraft is in a steep climbing turn or descending turn, correct bank, pitch, and power simultaneously. The bank attitude is corrected with reference to the turn-and-slip indicator (or attitude indicator if available). Pitch attitude is corrected with reference to the

altimeter, airspeed indicator, vertical speed indicator, and the attitude indicator (if available). Adjust power with reference to the power control instruments and the airspeed indicator.

d. Since the displacement of controls used in recoveries from unusual attitudes may be greater than those for normal flight, care must be taken in making adjustments as straight-and-level flight is approached. The instruments must be observed closely to avoid overcontrolling.

e. Errors common to recoveries from unusual attitudes include—

(1) Failure to make power correction.

(2) Failure to correct pitch attitude.

(3) Failure to correct bank attitude.

(4) Overcontrolling pitch and bank attitude.

(5) Excessive loss of altitude.

(6) Overcontrolling power.

4-27. AUTOROTATIONS

An autorotation is a descent without power in a helicopter. In the event of power failure or other emergencies requiring autorotation, prompt corrective action must be taken to insure positive control of the aircraft.

a. To enter autorotation, reduce collective pitch smoothly to maintain safe rotor rpm, and trim pedals to assure coordinated flight. The attitude of the aircraft should be level and the airspeed adjusted to the autorotative speed.

b. Practice instrument autorotations must be terminated with a power recovery. Power recoveries will be accomplished in accordance with the appropriate operator's manual and AR 95-1.

c. Errors common in autorotations and corrective actions include—

(1) Skidding and slipping on entry due to improper pedal trim.

(2) Improper airspeed or airspeed variation due to improper pitch attitude.

(3) Failure to maintain proper rotor rpm due to improper cross-check on rpm.

4-28. ACCELERATIONS AND DECELERATIONS

An acceleration or a deceleration is a proficiency maneuver that can be practiced during straight-and-level flight.

a. To practice this maneuver, the airspeed should be at normal cruise. Power changes should be executed in coordination with all available attitude instruments. Power changes of approximately 1 torque pound above and below cruise torque setting will result in an approximate 5-knot change in airspeed. Changes in attitude and trim control must be made throughout the maneuver to maintain altitude and desired heading.

b. To accelerate from normal cruise to high cruise, increase power 2 pounds of

torque above that required to maintain high cruise, adjusting attitude as necessary to maintain level flight. Then as the desired airspeed is approached, reduce power to high cruise power setting, adjusting attitude to maintain level flight.

c. To decelerate from high cruise to low cruise, reduce power 2 pounds of torque below that required to maintain low cruise and adjust attitude as necessary to maintain level flight. Then as the desired airspeed is approached, increase power to low cruise setting and adjust attitude to maintain appropriate altitude.

d. To accelerate from low cruise to normal cruise, increase power 2 pounds of torque above that required to maintain normal cruise and adjust attitude to maintain appropriate altitude. Then as the desired airspeed is approached, reduce power to normal cruise power setting and adjust attitude to maintain the desired altitude.

e. Errors common in accelerations and decelerations include—

(1) Improper use of power.

(2) Overcontrolling pitch attitude.

(3) Failure to maintain heading.

(4) Failure to maintain altitude.

(5) Overcontrolling power.

(6) Failure to maintain proper turn.

(7) Improper pedal adjustment.

[redacted]

Hydraulic systems failure is the loss of hydraulic pressure to the control system. It is evidenced by stiffness and feedback in the controls and by a warning light.

a. In the event of hydraulic systems failure—

(1) Maintain aircraft control.

(2) Adjust airspeed as necessary to obtain the most comfortable controllability.

(3) Complete emergency procedure in accordance with the appropriate operator's manual.

b. Hydraulic failure is simulated as prescribed in the appropriate aircraft Aircrew Training Manual (ATM).

CHAPTER 5

PROFICIENCY MANEUVERS

GENERAL

The maneuvers described in this chapter are practiced primarily to develop proficiency in power, pitch attitude, and bank attitude control, and to increase the aviator's speed in cross-checking.

VERTICAL S AND S-1

a. The *vertical S* (fig 5-1) consists of a series of climbs and descents. Throughout the maneuver, constant airspeed and heading are maintained. All climbs and descents are made at a constant rate as shown on the vertical speed indicator, and the reversing of vertical direction is made at specified altitudes. The time element is eliminated from the maneuver. The vertical S is entered as in a constant rate climb or descent. During the climb or descent, pitch attitude is adjusted on the attitude indicator to control the vertical speed, and airspeed is controlled with power. The heading indicator and attitude indicator are referred to for

bank control throughout the maneuver. The change from a climb to a descent requires the same amount of lead on altitude that is used in a *leveloff*. Power must be smoothly adjusted to the approximate setting for the desired descending airspeed at the same time that the pitch attitude is being adjusted to the approximate position for the desired rate of descent. The same control technique is used in changing from a descent to a climb. The frequency of reversing the vertical direction depends upon the type of aircraft used.

b. The climbs and descents will be at the same indicated rate as the amount of altitude to be gained or lost. Normally, in aircraft with a low rate-of-climb capability, the maneuver is accomplished by climbing 500 feet, descending 500 feet; climbing 400 feet, descending 400 feet; climbing 300 feet, descending 300 feet; and, climbing 200 feet, descending 200 feet. This completes the maneuver. High performance aircraft may accomplish the maneuver by changing altitudes of 1,000, 800, 600, and 400 feet, with corresponding rates of climb and descent. Trim control is especially important because of the constant changes in attitude and power throughout the maneuver. The frequency of these changes requires a rapid cross-check for precise control of the aircraft.

c. The *vertical S-1* (fig 5-2) is a combination of the vertical S and standard rate turns of 360°. Each turn is started in a climb and ends in a descent. The direction of the bank is reversed after each descent.

d. Errors common to the vertical S and S-1 maneuvers include—

(1) Failure to use the airspeed indicator properly for pitch control when changing the vertical direction.

(2) Overcontrol of pitch attitude when climbing and descending (indicated by excessive movement of the vertical speed indicator).

(3) Failure to use the proper altitude lead when reversing the vertical direction.

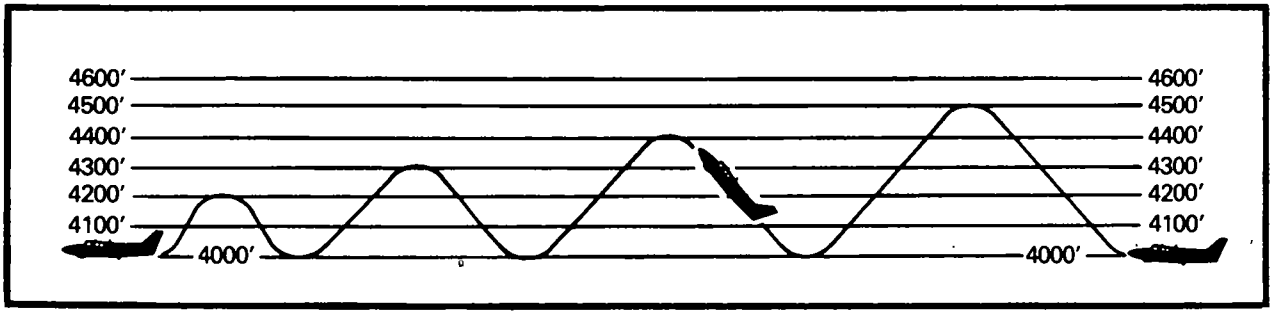


Figure 5-1. Vertical S.

(4) Failure to correct sufficiently for torque when power is changed.

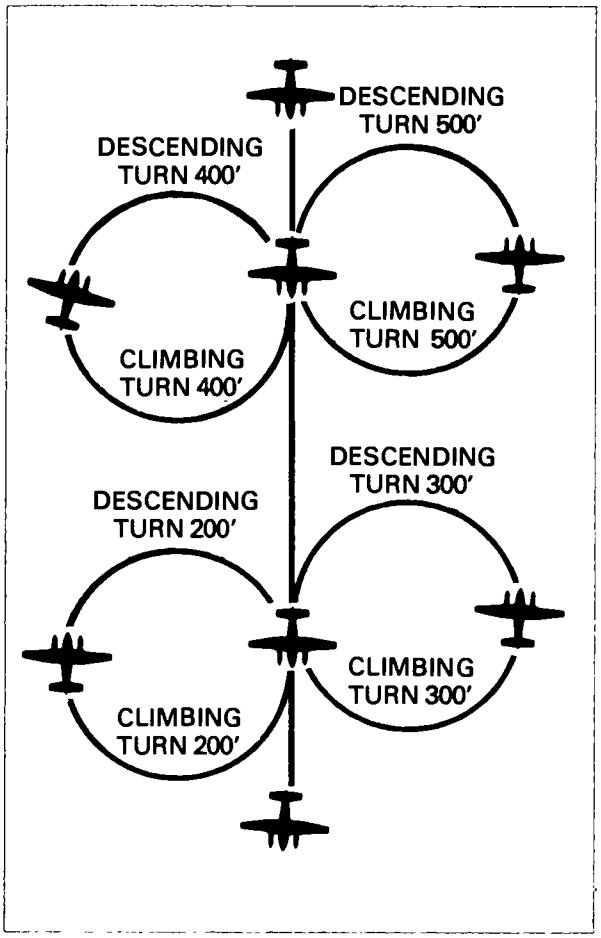


Figure 5-2. Vertical S-1.

5-3. PATTERN A

Pattern A (fig 5-3) is designed to give practice in maintaining straight-and-level flight and performing timed turns at definite time intervals. It is a combination of the procedures that will be used in the advanced phase of instrument training. As such, it is an invaluable experience in planning, precision timing, maintaining orientation, holding, performing procedure turns, and making approaches.

a. Prerequisites for successful performance of pattern A are—

(1) *Proficiency in performing timed turns without the use of the attitude and heading indicators.* Timing should begin when the second hand is on the 12-o'clock (preferable) or 6-o'clock position. All legs are 2 minutes long except the first, which is 1 minute. All turns are 3° per second timed turns. Timing for all turns begins and ends on a cardinal point on the clock. Timing for each leg of the pattern begins at the same moment that pressure is applied on the controls to roll the aircraft out of the preceding turn, even though the aircraft is still turning and is not on the desired heading.

(2) *Understanding of the proper use of the magnetic compass and awareness of its errors.* The pattern may be started on any heading; however, initial practice should be accomplished on cardinal headings for simplification.

(3) *Familiarity with the pattern and knowledge of the power settings for the different airspeeds used.*

b. When the aircraft is in straight flight and a few seconds have been allowed for the magnetic compass to stop oscillating, the

compass heading is noted. If the aircraft is not on the correct compass heading, a correction is made toward the desired heading before changing the airspeed. On headings of north and south, this correction must be a timed turn; however, in the vicinity of east and west, a shallow bank and turn directly to the heading is possible since there is no turning error on headings of east and west.

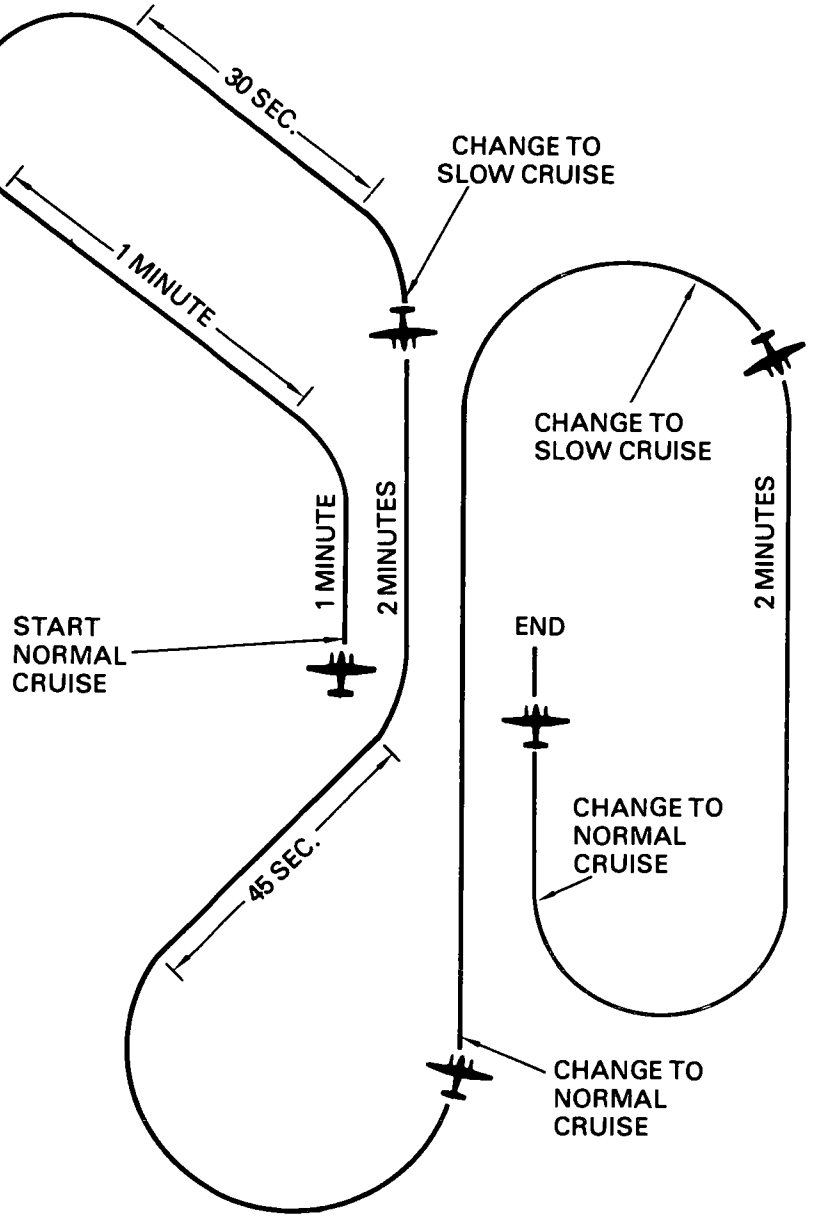


Figure 5-3. Pattern A.

c. The airspeed should be changed immediately if a correction of heading is not required. When the turn-and-slip indicator is the only bank instrument available, it must be observed closely at all times. The magnetic compass can be used only to determine the accuracy of the heading. The altimeter is used with the vertical speed indicator to maintain precise pitch control. A rapid and efficient cross-check is required during changes of airspeed, so that corrections can be applied immediately.

d. Errors common in the pattern A maneuver include—

(1) Failure to control bank properly in turns.

(2) Failure to maintain heading and altitude.

(3) Attempting to use the compass as a bank instrument.

(4) Poor bank control during changes in airspeed.

(5) Failure to make allowances for an incorrectly calibrated turn needle during the timed turns.

5-4. PATTERN B

a. *Pattern B* (fig 5-4) is designed to give further practice in the procedures used during the advanced phase and to combine most of the maneuvers previously performed. It is essentially the same maneuver as pattern A with the following exceptions:

(1) All available instruments are used.

(2) The airspeed is changed during the turns.

(3) A prelanding check is completed on the fourth leg.

(4) Descents at 500 feet per minute (fpm) are made during the maneuver.

(5) The airspeed is maintained following the final turn, and a descent of 500 fpm is established, followed by a go-around after descending 1,000 feet.

b. The timing is consecutive, since the time for each leg starts when the time for the previous turn has elapsed regardless of the bank attitude of the aircraft. Timing is simplified if the pattern is always started when the second hand of the clock indicates the 12-o'clock position. The pattern may be memorized; however, using a card will give practice that will be valuable in accomplishing advanced work. Planning should take place when flying straight and level on the legs. The pattern can be started on any heading, but initial practice should be done on cardinal headings.

c. Errors common in the pattern B maneuver include—

(1) Failure to control rate of turn.

(2) Failure to maintain heading and altitude.

(3) Attempting to use the compass as a bank instrument.

(4) Poor bank control during changes in airspeed.

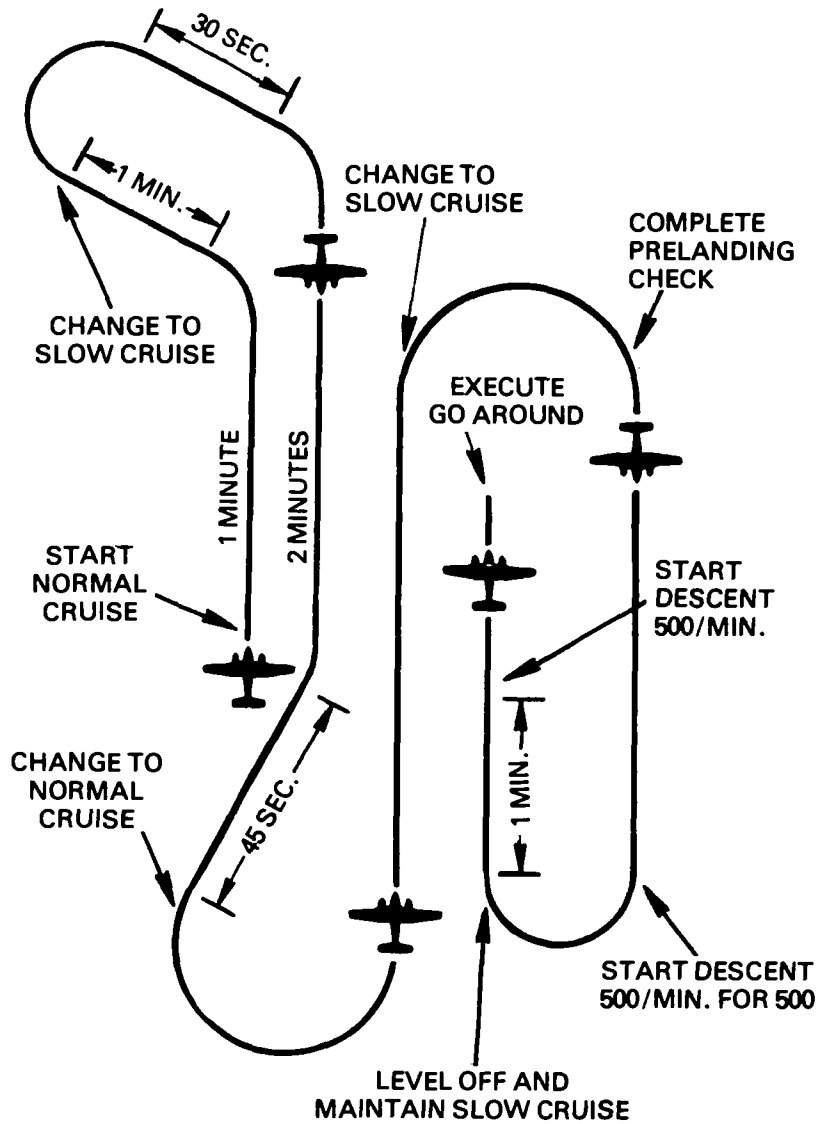


Figure 5-4. Pattern B.

PART TWO

AIR NAVIGATION

The art of directing the aircraft along a desired course and determining its position along this course at any time.

CHAPTER 6 GENERAL

7 BASIC CONCEPTS OF AIR NAVIGATION

8 NAVIGATION CHARTS

9 PLOTTING AND MEASURING

10 INSTRUMENTS USED FOR DEAD-RECKONING NAVIGATION

11 WIND AND ITS EFFECTS

12 THE DEAD-RECKONING (DR) COMPUTER

PART TWO

AIR NAVIGATION CONTINUED

CHAPTER 13 RADIO PRINCIPLES

14 VHF OMNIDIRECTIONAL RANGE SYSTEM (VOR)

15 AUTOMATIC DIRECTION FINDER (ADF) AND MANUAL LOOP PROCEDURES

16 THE DOPPLER NAVIGATION SET AND COMMAND INSTRUMENT SYSTEM

17 THE INERTIAL NAVIGATION SET AN/ASN-86

18 TACTICAL AIR NAVIGATION (TACAN)

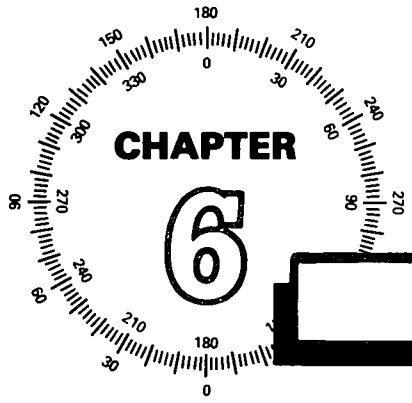
19 INTRODUCTION TO INSTRUMENT APPROACH PROCEDURES

20 VHF OMNIDIRECTIONAL RANGE (VOR) AND NONDIRECTIONAL BEACON (NDB) APPROACHES

21 INSTRUMENT LANDING SYSTEM (ILS)

22 RADAR

23 TACTICAL INSTRUMENT FLIGHT



CHAPTER 6

GENERAL

NAVIGATION

Air navigation is defined as the art of directing the aircraft along a desired course and determining its position along this course at any time. Such navigation may be by means of pilotage, dead reckoning, or radio navigational aids, and includes those procedures which are used during instrument flight in directing the aircraft to a safe landing.

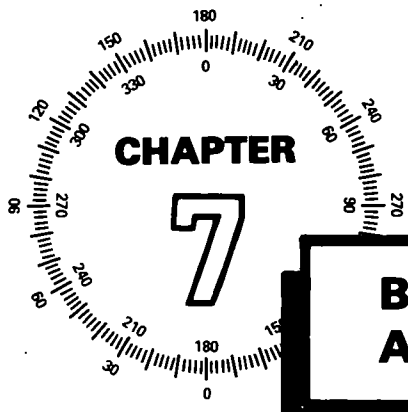
[redacted]

This discussion includes the following information:

a. Basic concepts of air navigation and the use of the implements of air navigation which assist the Army aviator in planning and completing a flight by means of pilotage and/or dead reckoning.

b. Employment of radio navigational aids in flight.

c. Facilities and procedures peculiar to instrument approaches.



CHAPTER 7

BASIC CONCEPTS OF AIR NAVIGATION

Section I. THE EARTH IN SPACE

[redacted]

A perfect sphere is a body whose surface is at all points equidistant from a point within, called its *center*. Any straight line which passes from one side, through the center of the sphere, to the opposite side is called the *diameter* of the sphere. Although the Earth is actually a spheroid (being slightly flattened at the poles), for navigational purposes it is considered a perfect sphere.

[redacted]

The diameter of the Earth, around which the spherical body rotates, is an imaginary straight line called the *axis*. The points formed by the intersection of the axis with the Earth's surface are the North and South Poles. Any point on the Earth's surface, except the North and South Poles, completes one rotation around the axis every 24 hours.

[redacted]

As the Earth rotates, it also revolves around the Sun in an elliptical path (fig 7-1), completing one orbit each year.

[redacted]

The axis of the Earth is inclined approximately 23½° from the perpendicular to its plane of revolution. This inclination is such that the North Pole points generally toward the North Star (Polaris).

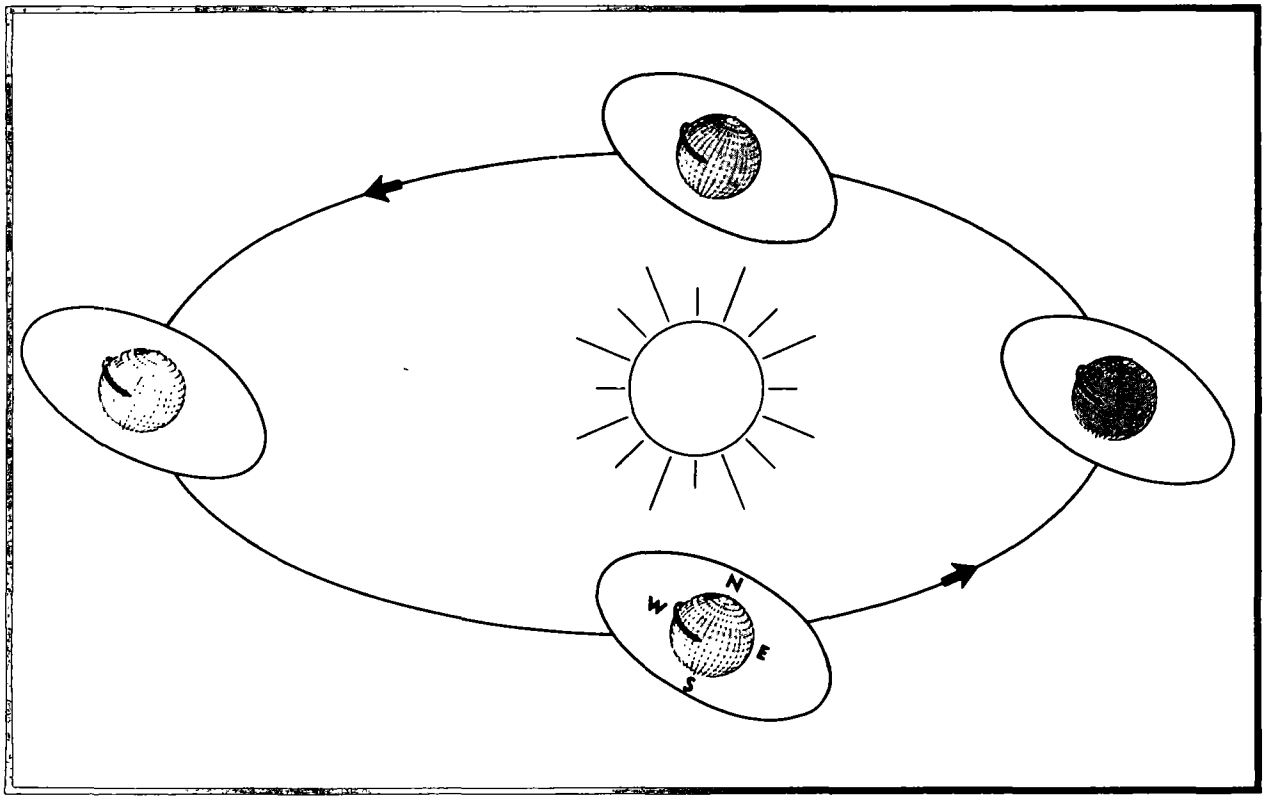


Figure 7-1. West to east rotation of the Earth and its revolution around the Sun.

Section II. MEASURING POSITION ON THE EARTH

[redacted]

To identify the location of a point on the surface of the Earth, a universal system of expressing geographical position without reference to physical features is a necessity. Such a system, known as a *coordinate* or *grid* system (fig 7-2), designates location or position and expresses angular magnitude with respect to two reference lines (meridians and parallels) which intersect at right angles. By reference to these lines, any point may be accurately located. This system of coordinates is formed by the

intersecting of great and small circles (para 7-6a).

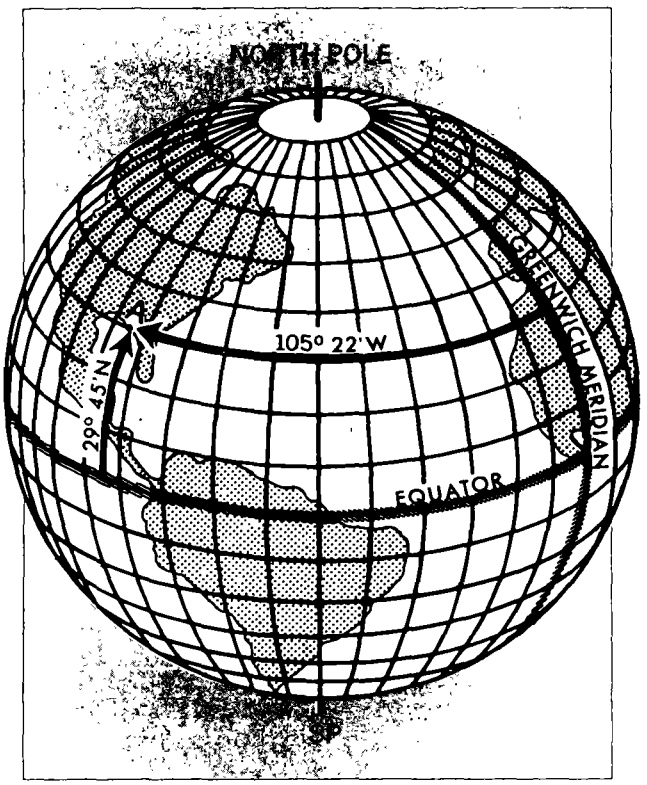


Figure 7-2. Coordinate (grid) system.

[redacted]

a. *Great and Small Circles.* The straight cut of a plane through a sphere forms a *circle.* If the cut passes through the center of the Earth, the circle formed is a *great circle.* This is the largest circle that can be cut from a sphere. Any other circle, regardless of size, is called a *small circle,* since the plane of a small circle does not pass through the center of the sphere and, hence, will not divide the sphere in half (fig 7-3).

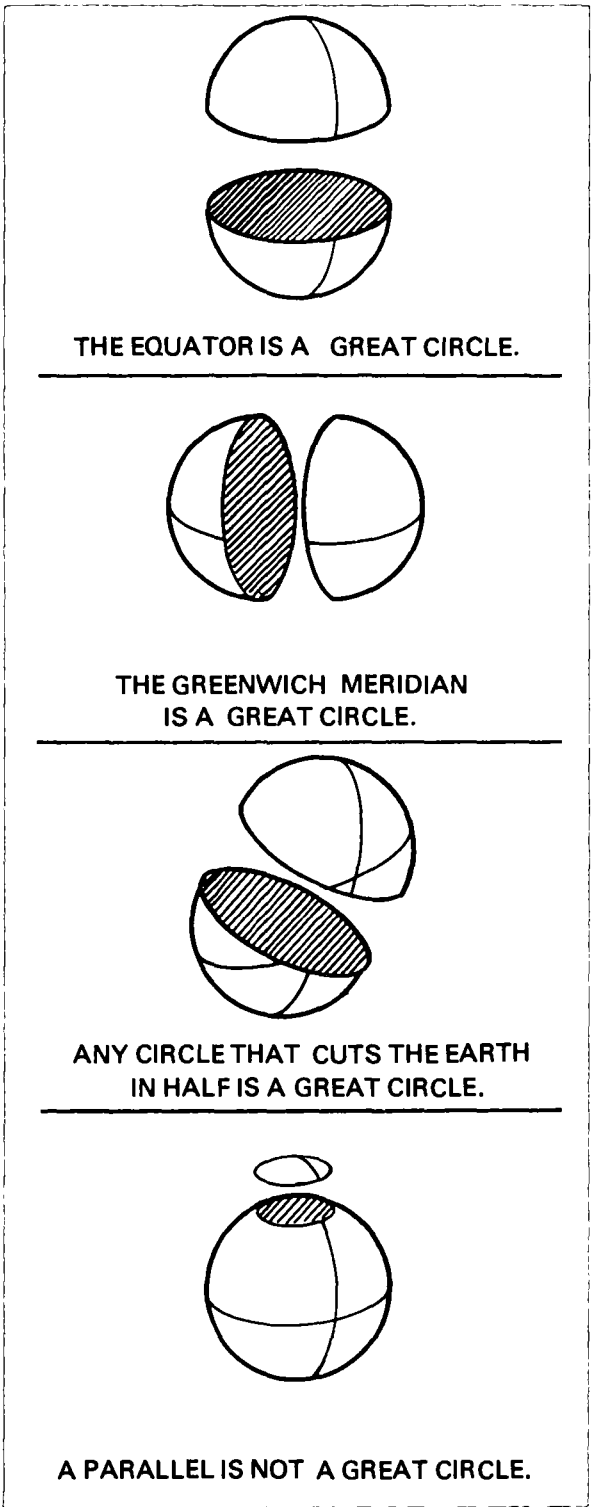


Figure 7-3. Great and small circles.

b. *Arcs and Their Measurement.* Arcs are *segments of circles* and are measured in degrees, minutes, and seconds. A degree (°) is 1/360 of the circumference of a circle; thus, if any circle is divided into 360 equal arcs, each arc is 1° in length, regardless of the size of the circle. A minute (') is 1/60 of 1°, a second ('') is 1/60 of 1 minute.

c. *The Central Angle.* Straight lines drawn from each end of an arc to the center of a circle form an angle at the center called the *central angle.* Angles, like arcs, are measured in degrees, minutes, and seconds. The angle at the center of the circle contains the same number of degrees, minutes, and seconds as the arc which it subtends. Each line from the center of the circle to its periphery is a *radius.*

d. *Angular and Linear Distances.* The angular distance between any two points on a circle can be expressed in degrees, minutes, and seconds of arc. This distance is actually a measure of the central angle and is independent of the size of the circle. The angular distance depends upon that portion of the circle which separates the two points. For any given angle, the linear distance between two points on the circle (an arc, fig 7-4) varies with the size of the circle; i.e., with the length of the radius.

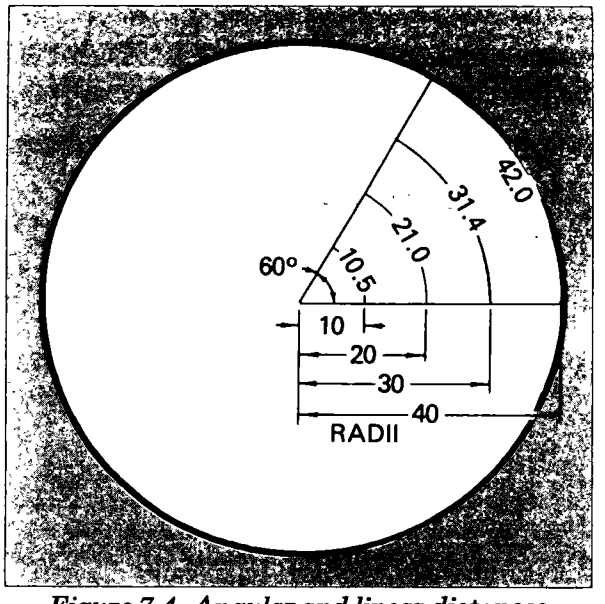


Figure 7-4. Angular and linear distances.

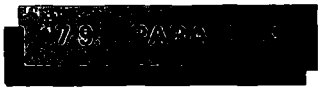
[redacted]

The axis of the Earth is the only distinctive, natural geometric line of the Earth. The North and South Poles are distinct points on the Earth and are used as central points for one set of reference circles known as *parallels of latitude.* The only great circle of this set of circles is the Equator (fig 7-2).

[redacted]

The Equator is a great circle located halfway between the North and South Poles and serves as a reference line for all parallels of latitude (fig 7-2). Since the poles are 180° apart, every point on the Equator is 90° from each pole. The plane of

the Equator is at right angles to the Earth's axis and divides the Earth into the Northern and Southern Hemispheres.



Any small circle whose plane is parallel with the plane of the Equator is a parallel of latitude (fig 7-2). Every point on a given parallel is equidistant from the Equator, the poles, and any other parallel. The Equator and all parallels are concentric around the polar axis. An infinite number of parallels may be drawn; however, only a few are shown on the globe. A parallel on the Earth's surface is designated by its angular measurement north or south of the Equator; e.g., point A (fig. 7-2) is on a parallel 29°45' north of the Equator.

A great circle passing through both poles is called a *meridian of longitude* (fig 7-2). As with parallels, there may be an infinite number of meridians even though few are shown on the globe. The meridian passing through the observatory at Greenwich, England, has arbitrarily been selected as the reference or *prime meridian.* All other meridians are designated by their angular distance east or west of the prime meridian; e.g., point A (fig 7-2) is on a meridian 105°22' west of the Greenwich meridian.

a. *Latitude.* The latitude of a point on the surface of the Earth is its angular measurement north or south of the Equator measured on the plane of the meridian passing through the point. Latitudes range from 0° at the Equator to 90° north or south at the poles.

b. *Longitude.* The longitude of a point is its angular measurement east or west of the prime (Greenwich) meridian, measured on the plane of the Equator or of a parallel. Longitude ranges from 0° at the prime meridian to 180° at the meridian diametrically opposite the prime meridian (halfway around the world at the international date line).

c. *Parallels of Latitude and Meridians of Longitude.* Naming the parallel and meridian which passes through a point is essentially the same as giving its coordinates. Each parallel of latitude is designated according to its angular measurement north or south from the Equator and each meridian of longitude is designated according to its angular measurement east or west of the prime meridian. A meridian of longitude is a line, but longitude is an angle; a parallel of latitude is a line, but latitude is an angle. In giving the coordinates of a point, latitude is given first, followed by the longitude; *for example,* point A (fig 7-2) is positioned at latitude 29°45'N, longitude 105°22'W.

Section III. MEASURING DIRECTION ON THE EARTH

7-12. GENERAL

In air navigation, directions are indicated both by use of *cardinal points* (north, east, south, west) or *intercardinal points* (northeast, southeast, southwest, etc.) of the compass and by numbers (degrees) (fig 7-5).

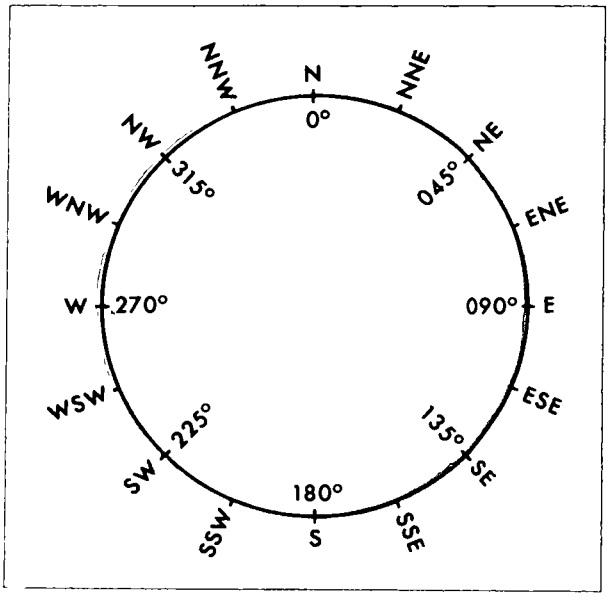


Figure 7-5. Compass rose.

7-13. MEASURING DIRECTION

The compass rose (fig 7-5) divides the horizon (fig 7-6) into 360 parts or degrees. Starting with north as 0° and continuing clockwise through east, south, and west, directions are expressed in degrees measured from north (0°). North may be expressed as 360°. East is 090°, and west is 270°. Figure 7-7 shows point B in a direction of 045° (northeast) and point C in a direction of 270° (west) of aircraft A. Aircraft A is headed in a direction of 120°. A line by itself does not indicate a single direction; arrows or labels along the line are used to indicate the intended direction. Note that the direction of C *from* A (270°) is not the same as the direction of C to A (090°), even though drawn as one line. The direction of a line is measured from its point of origin and labeled by the angle the line forms with an intersecting meridian. In figure 7-7, the direction from A is measured from point A. If the meridians are drawn as parallel lines, the direction of a straight line may be measured at any point along the line. In measuring the direction from C to A (A from C), measurement is made with reference to the mean meridian (DE) of points A and C because the meridians in figure 7-7 are not parallel; i.e., they converge toward the north as do the meridians on most aerial navigation charts.

Figure 7-6. The horizon as a compass rose.

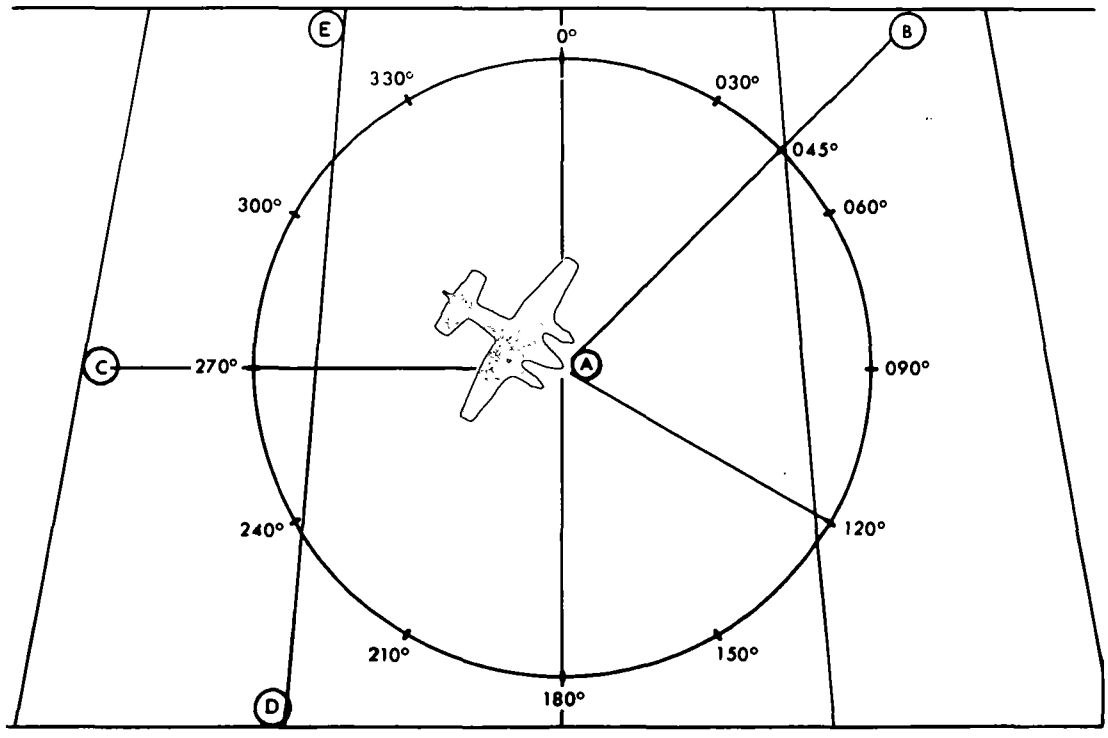


Figure 7-7. Measurement of direction.

7-14. COURSE

The direction which an aircraft is to fly to reach a given destination is the *course* to that destination. Therefore, the course from A to C (fig 7-7) is 270°.

7-15. RHUMB LINE (DEFINITION)

The rhumb line is a line of constant direction that crosses successive meridians at the same oblique angle (fig 7-8). Parallels of latitude, the Equator, and meridians are often called *rhumb lines* even though they do not fully conform with the definition. A true rhumb line, if continued, will spiral toward the poles, never quite reaching either of them. Such a spiral is called a *loxodromic curve* (fig 7-8).

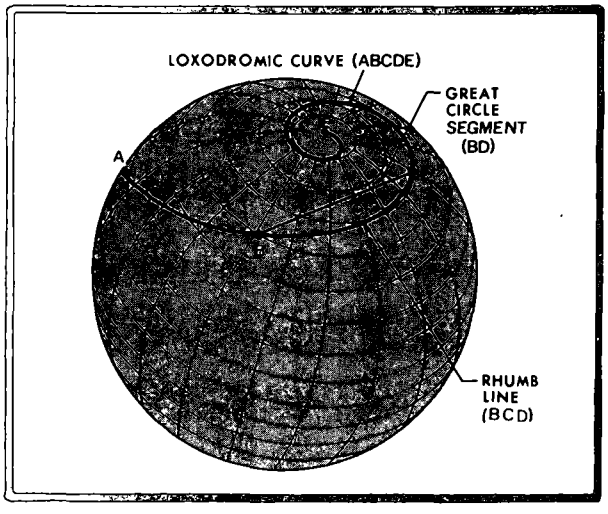


Figure 7-8. Rhumb line, loxodromic curve, and great circle.

[redacted]

a. *Distance.* The length of a line joining two points is its distance. The most common unit for measuring distance in navigation is the mile. Since the word "mile" does not define an exact distance, it is important to specify the type of mile.

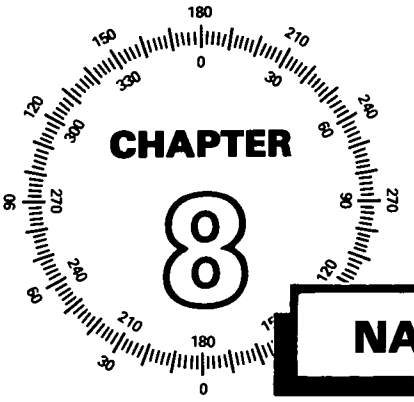
b. *Statute Mile.* In the United States, 1 mile is defined by statute as being 1,760 yards or 5,280 feet. This is called *a US statute mile.* There are some differences in the legal definition in other countries. With the growth of cross-country flying and the development of better aviation charts, the statute mile is rapidly becoming obsolete. Aviators will, however, encounter statute mile indications on some charts, plotters, and airspeed indicators.

c. *Nautical Mile.* Military airmen use the nautical mile as a unit of distance. The nautical mile (6,076.1 feet) is equivalent to 1 minute of latitude, or approximately 1.15 statute miles. A statute mile is approximately 0.87 nautical miles.

NOTE: The only requirement that nautical miles be used in air navigation pertains to filing flight plans. However, nautical miles are more convenient since distances on published aeronautical charts are shown in nautical miles, windspeeds are reported in nautical miles per hour (knots), and most airspeed indicators are calibrated in nautical units. If navigational data contains mixed units, convert *all* measurements either to nautical miles or to statute miles.

7-17. GREAT CIRCLE DISTANCE

The shortest distance between two points on the surface of the Earth lies along any minor arc of a great circle passing through both points. A minor arc of the great circle between two points is more nearly a straight line than is the arc of any other circle which can be drawn between these points (fig 7-8).



NAVIGATION CHARTS

Section I. CHART PROJECTIONS

81. GENERAL

An *air navigation chart* is a diagrammatic representation of the Earth's surface. The chart shows elevation; cities and towns; principal highways and railroads; oceans, lakes, and rivers; radio aids to navigation; danger areas; and other features useful to the navigator.

82. SCALE

a. *General.* The *scale* of the charts is the ratio between the distance on a chart and the distance it represents on the Earth. A chart showing the entire surface of the Earth is drawn to a small scale for convenient size. A chart covering a small area and much detail is drawn to a larger scale.

b. *Types of Scales.* The scale of a chart may be expressed simply, such as "1 inch equals 30 miles." This means that a ground distance 30 miles long is 1 inch long on the chart. On aeronautical charts, the scale is shown in representative fractions and/or graphic scales.

(1) *Representative fraction.* A scale may be given as a representative fraction such as 1:500,000 or 1/500,000. This means that 1 unit on the chart represents 500,000 units of the same dimension on the Earth. *For example,* 1 inch on a chart may represent 500,000 inches on the Earth or approximately 6.9 nautical miles or 8 statute miles.

(2) *Graphic scale.* A graphic scale (fig 8-1) shows the distance on a chart labeled in terms of the actual distance it represents on the Earth. The distance between parallels of latitude is a convenient graphic scale since 1° of latitude always equals 60 nautical miles. Meridians are often divided into minutes of latitude, with each division representing 1 nautical mile.

[redacted]

Distortion is the misrepresentation of direction, shape, and relative size of features on the Earth's surface which occurs when the Earth's round surface is projected onto a flat chart surface. A globe is the only means of representing the entire surface of the Earth without distortion.

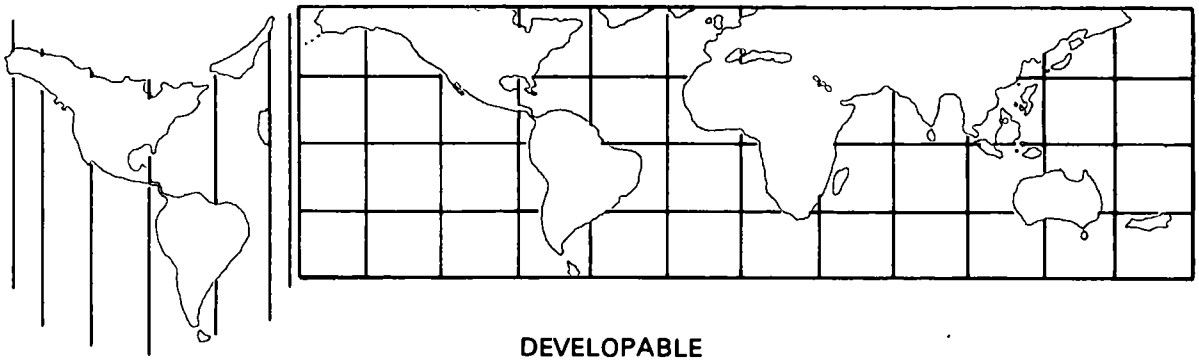
a. *Developable Surfaces.* A *developable* surface (fig 8-2) is a curved surface such as a plane, cylinder, or cone that can be flattened without tearing, stretching, or wrinkling.

b. *Nondevelopable Surfaces.* The surface of a sphere or spheroid is *nondevelopable* because no part of it can be laid out flat without distortion. This can be understood by attempting to flatten half of an orange peel. However a *small* piece of orange peel, because it is nearly flat, can be flattened with little stretching or tearing. Likewise, a small area of the Earth's surface which is nearly flat can be represented on a flat surface with little distortion (fig 8-2). Distortion becomes a serious problem in charting large areas and can never be completely eliminated. It can, however, be controlled and systematized; i.e., a chart for a particular purpose can be drawn so as to minimize the type of distortion which is most detrimental.

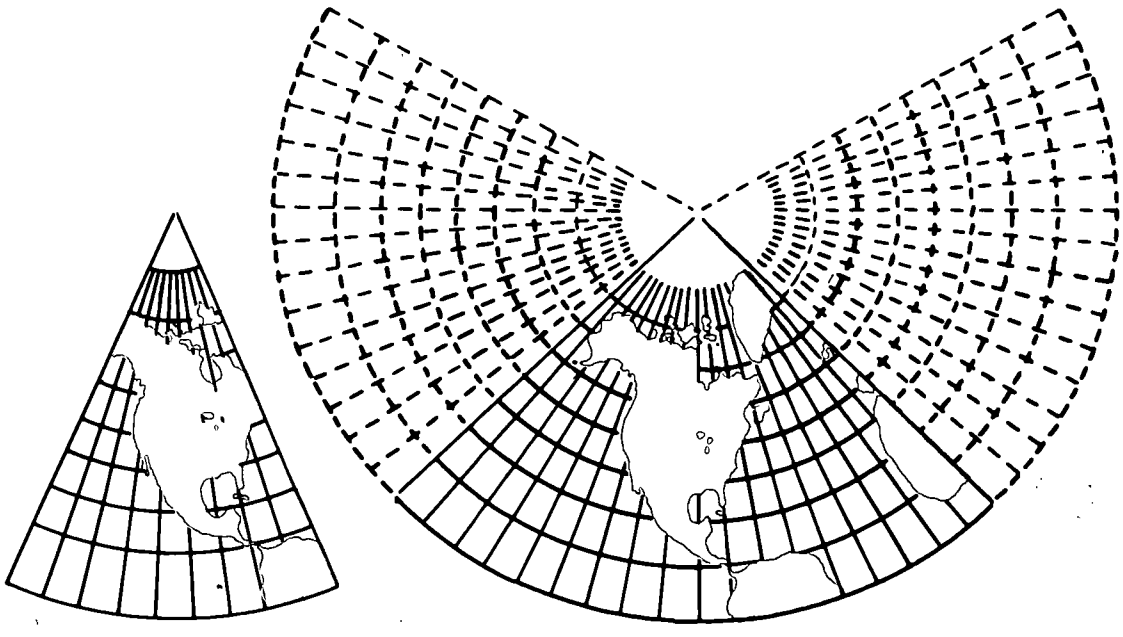
[redacted]

Each type of chart has distinctive features which make it preferable for certain uses; no one chart is best for all

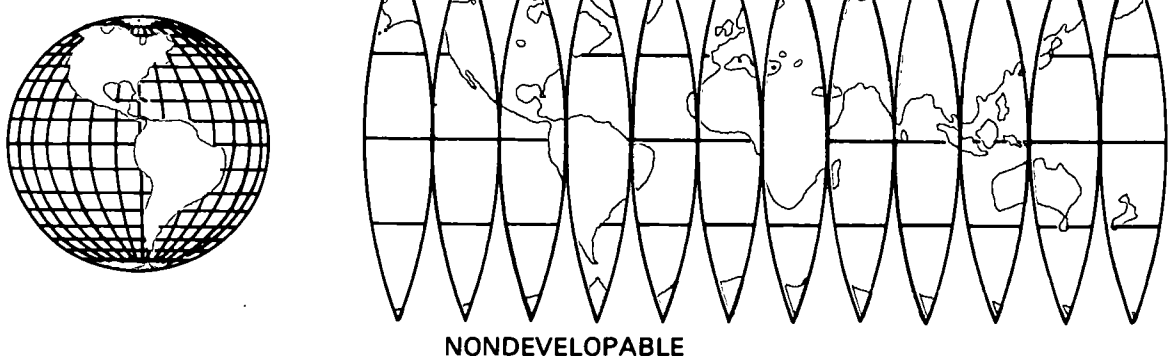
Figure 8-1. Graphic scale.



DEVELOPABLE



DEVELOPABLE



NONDEVELOPABLE

Figure 8-2. Developable and nondevelopable surfaces.

uses. If it were possible to construct a perfect chart, the chart would have the following: true shape of all physical features, correct angular relationship (conformality), representation of areas in their correct relative proportions, true scale value for measuring distances, and great circles and rhumb lines represented as straight lines. It is possible to obtain one and sometimes more than one of the above properties in any one projection, but it is impossible to retain all of them. *For example,* a chart cannot be both conformal and equal area. Desirable, but secondary chart properties are—ease in finding and plotting coordinates of points, ease in joining two or more charts, cardinal directions parallel throughout the chart, and simplicity and ease in construction.

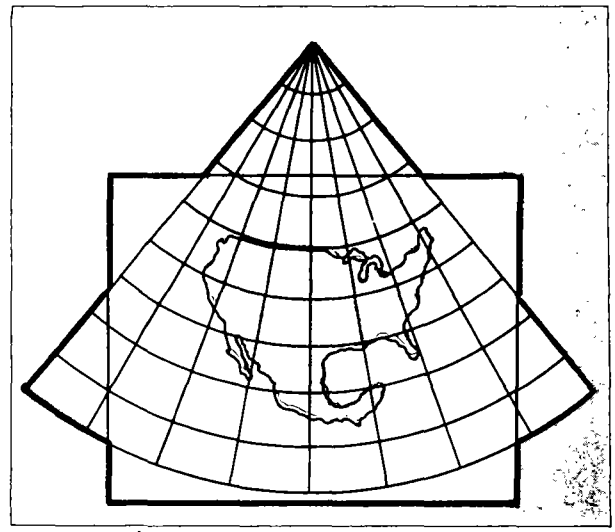


Figure 8-3. Appearance of the Lambert projection graticule.

[redacted]

a. *General.* Exact coordinates of any point on the Earth may be found by astronomical means. With reference to control points established in this manner, the exact location of nearby features may be found by geographic survey or by aerial photography. A chart can then be made by drawing the established geographical features on a framework of meridians and parallels known as a *graticule* (fig 8-3). Once the graticule is drawn, features may be plotted in their correct positions with references to meridians and parallels.

b. *Form and Size.* The form of the graticule determines the general characteristics and appearance of the chart; its size determines the scale. Since meridians and parallels cannot be shown on a plane surface exactly as they would appear on a sphere, there is no perfect method of constructing the graticule. *For example,* the meridians and parallels may be shown as straight lines, as variously curved lines, or some as straight and some as curved lines; they may be spaced in various ways and may intersect at various angles.

[redacted]

a. *Definition.* The method of representing all or part of the surface of a sphere or spheroid on a plane surface is known as *projection.* The actual projection of a graticule is accomplished by application of mathematical formulas.

b. *Classifications.* Projections are classified primarily as to the type of developable surface (fig 8-2) to which the spherical or spheroidal surface is transferred. They are sometimes further classified as to whether the projection (but not necessarily the chart made by it) is centered on the Equator (equatorial), a pole (polar), or some point or line between the Equator and the poles (oblique) or tangent at a meridional (transverse). Some cartographers drop the term "oblique" and call all such projections "transverse." Chart projections most commonly used in air navigation are the Lambert conical, the Mercator cylindrical, and the polar stereographic, all three of which are conformal projections (para 8-7d). (*Stereography* is the art of representing forms of the solid bodies on a plane surface.)

c. *Purpose of Charts.* Charts are used in navigation principally for two purposes—chart reading and plotting and measuring. Chart *reading* is the location of one's position by identification of landmarks (para 9-1). *Plotting* refers to establishment of points and lines on a chart. *Measuring* means measurement of direction and distance on a chart (para 10-1).

8-7. LAMBERT CONFORMAL PROJECTION

a. *Appearance of the Graticule.* The Lambert conformal projection (Lambert chart) is a conic projection using the cone for a developable surface. All meridians are straight lines meeting at the apex of the cone. All parallels are concentric circles, the center of which is also the apex of the cone. Meridians and parallels intersect at right angles and the angle formed by any two lines is correctly represented (fig 8-3).

b. *Standard Parallels.* The cone intersects the sphere at two parallels (fig 8-4). The parallels are known as standard parallels for the area to be represented. In general, for equal distribution of scale error, the standard parallels are chosen at one-sixth and five-sixths of the total length of that portion of the meridian to be represented.

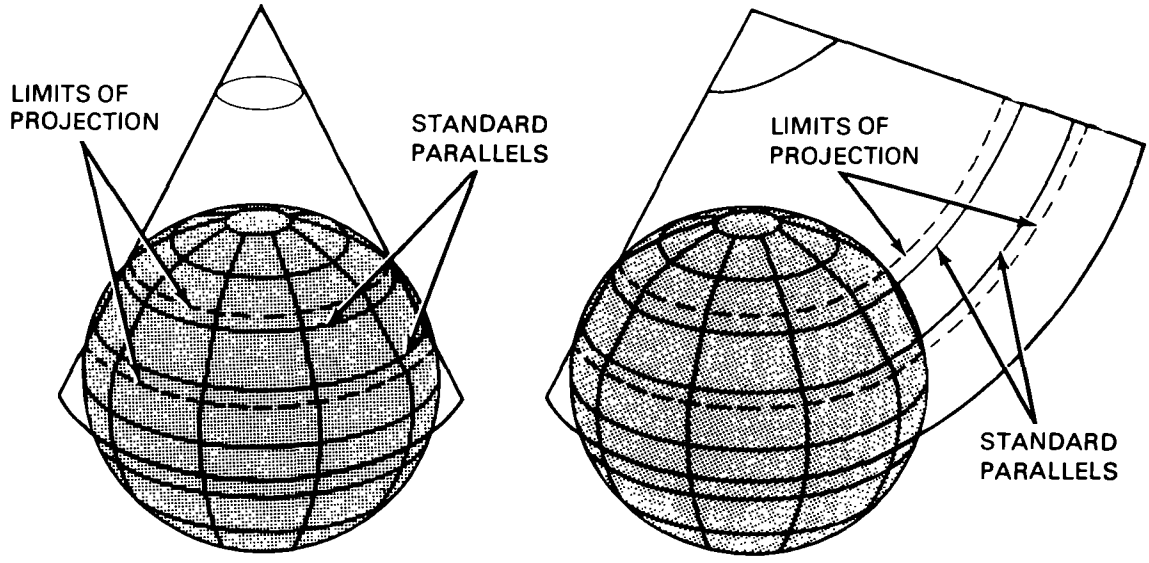


Figure 8-4. Standard parallels on Lambert conformal chart.

c. *Accuracy.* Along the two standard parallels, areas are represented in true scale. Between the standard parallels, the scale will be too small; beyond them, too large. For practical purposes, the scale can be considered constant for a large scale chart of a small area (fig 8-5). Accuracy is greatest for charts of predominantly east-west dimensions.

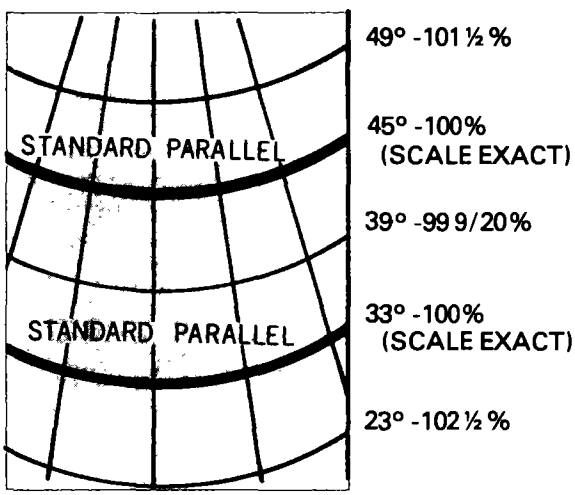


Figure 8-5. Variation of scale on typical Lambert projection.

d. *Conformality.* The Lambert projection is conformal because the scale is practically uniform in all directions about any point, and the angles formed by parallels and meridians are shown correctly. Because of the scale uniformity, areas retain true shape (fig 8-6).

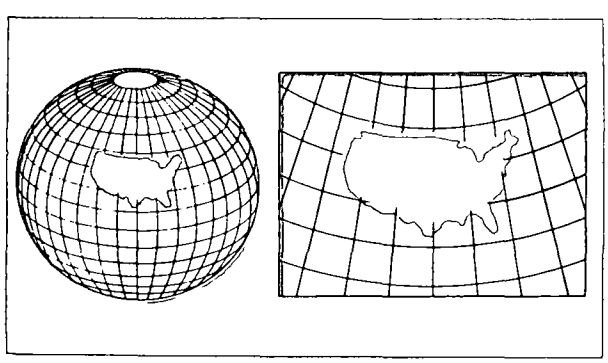


Figure 8-6. Areas and angles (Lambert).

e. *Great Circle vs. Straight Line.* Any straight line on a Lambert conformal conic chart is nearly a great circle (fig 8-7). In the distance of 2,572 statute miles between San Francisco and New York, a great circle and a straight line connecting them on a Lambert chart are only 9½ miles apart at midlongitude. For shorter distances, the difference is negligible. For all practical purposes, if a flight is only a few hundred miles long, a straight line may be considered a segment of a great circle.

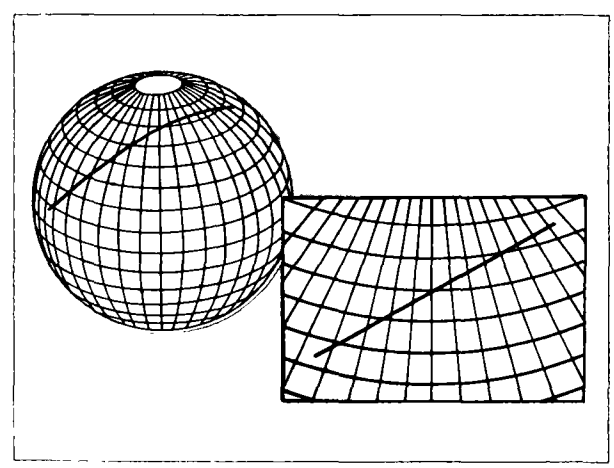


Figure 8-7. Great circle vs. straight line on a Lambert chart.

f. *Rhumb Line on a Lamber Chart.* A rhumb line on a Lambert chart is a curved line that cuts all meridians at the same angle. The closer its direction is to east-west, the more a rhumb line departs from a straight line. Over distances of 100 to 200 miles, in the latitude of the United States, a rhumb line departs little from a straight line; but over long distances, the

difference becomes large. Between San Francisco and New York, the length of a rhumb line differs from a straight line by about 170 miles. An accurate rhumb line cannot be drawn on a Lambert chart, but it can be approximated by a series of short straight lines.

g. *Use.* The constant scale and conformity of Lambert charts place them among the best charts for air navigation. They are suitable for navigation, using long-distance radio bearings; and they are superior to Mercator charts (para 8-8) for problems involving long distances and true directions. However, for plotting positions and measuring rhumb line directions, they are inferior to Mercator charts.

8-8. MERCATOR PROJECTION

a. *Description.* The Mercator chart is a cylindrical projection. Meridians appear as straight lines which are equidistant and parallel. Parallels of latitude are parallel to each other and perpendicular to the meridians. The distance between parallels increases with an increase in latitude. Since the meridians are parallel to each other, the east-west scale is increased with an increase in latitude. Consequently, parallels must be placed in such a manner that the north-south scale increases proportionately. As a result, the scale at any point is constant in all directions. Since meridians and parallels intersect at right angles as on the Earth, all angles are shown correctly. Every rhumb line appears as a straight line, and every straight line is constant in direction. The Equator and the meridians are the only great circles which appear as straight lines; all other great circles appear as curved lines (fig 8-8).

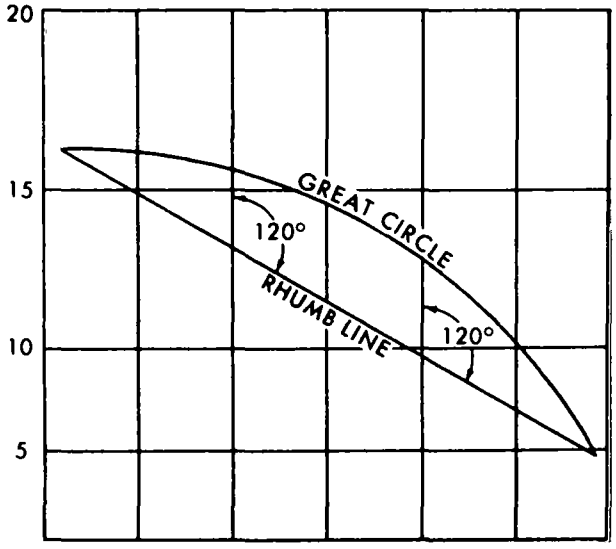


Figure 8-8. Mercator chart showing rhumb line vs. great circle.

b. *Use, Advantages, Disadvantages.* The Mercator chart is used in air navigation only for long-range overwater flying. Its greatest advantage is that a rhumb line on the chart is a straight line. Plotting is easier because of the rectangular graticule. On the other hand, long-range radio bearings cannot be plotted without special corrections. Because of the expanding scale of this chart, distances are difficult to measure.

8-9. POLAR STEREOGRAPHIC PROJECTION

a. *General.* The polar stereographic projection (fig 8-9) is based on a plane,

tangent at the pole, with the point of projection at the opposite pole. Meridians are straight lines converging at the pole. Parallels are concentric circles with the pole as their common center. For the world aeronautical chart (WAC) series (para 8-11), the polar stereographic chart is modified by using a secant plant, a line intersecting a curve at two or more points (fig 8-10). This modification makes the polar stereographic and Lambert charts the same scale at 80° latitude. The polar stereographic chart becomes true scale at 80°14' since the secant plane intersects the Earth's surface at that latitude, with the scale decreasing as the pole is approached. The polar stereographic chart is the best chart for navigation in polar regions.

b. *Area of Coverage.* A polar stereographic chart may include a whole hemisphere; however, a chart used for air navigation will not extend more than 20° or 30° from the pole.

c. *Scale.* Since the interval between parallels increases with distance from the pole, the north-south scale also increases away from the pole. The east-west scale increases in the same proportion, so that at any point the scale is constant in all directions. For all practical purposes, the scale is constant within the limits of a navigational chart.

d. *Angles.* All angles are correctly shown since meridians appear as radii of circles representing parallels, and meridians and parallels intersect at 90° angles on the chart.

e. *Straight Lines vs. Rhumb Lines vs. Great Circles.* Meridians, which are great circles, appear as straight lines; hence, any great circle passing through the center of the chart appears as a straight line. Other great circles appear as slightly curved; however, the closer they are to center, the straighter they appear. Within the limits of a navigational chart, a great circle is shown as a straight line and rhumb lines appear as curved lines.

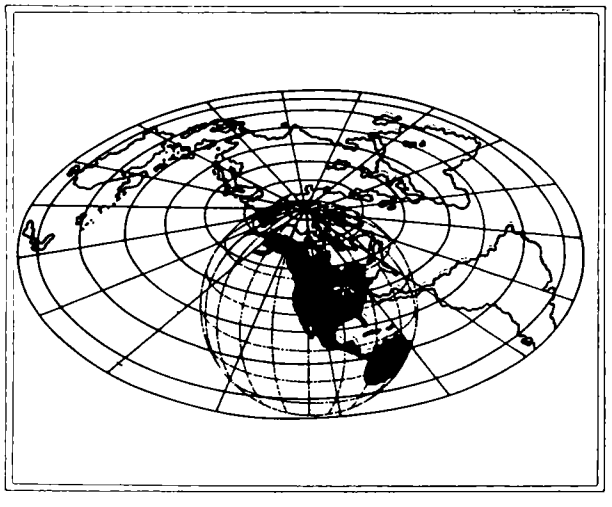


Figure 8-9. The polar stereographic projection.

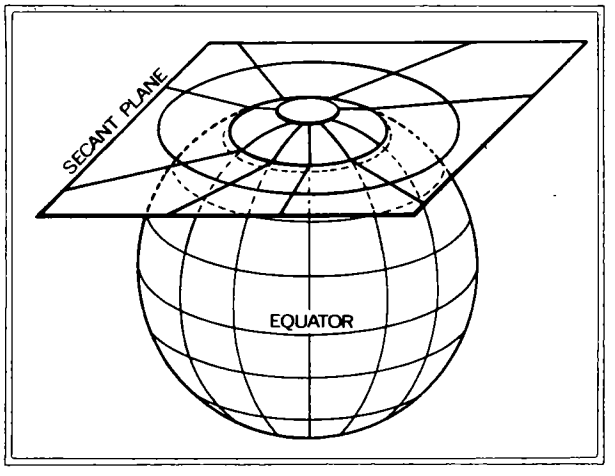


Figure 8-10. Modified polar stereographic projection.

Section II. AERONAUTICAL CHARTS

8-10. SECTIONAL AERONAUTICAL CHARTS

a. *General.* Sectional aeronautical charts are Lambert conformal charts published by the National Ocean Survey, National Oceanic and Atmospheric Administration, United States Department of Commerce. The scale is 1:500,000 (1 inch equals approximately 6.9 nautical miles or about 8 statute miles). These charts are intended primarily for flights of short duration using pilotage (visual flight), but are suitable for other forms of navigation. The large scale of the sectional chart permits information to be included in great detail. A listing of aeronautical symbols and other useful information is printed on the inside and outside borders of the chart. The effective date and the date the chart will become obsolete are printed on the front or title page ("b" through "f" below list some of the features of these charts).

b. *Terrain.* The portrayal of terrain on the charts will emphasize land forms by relief shading and will also include contours, elevation tints, and a generous depiction of a number of spot elevations. The maximum terrain elevation within each 30' longitude and 30' latitude area will be dramatically shown in large size type.

c. *Cultural.* Cultural features, such as railroads and major roads and, in sparsely settled areas, even dirt roads or paths, may be shown. Cities and towns, mines, lookout towers, and many other good landmarks are indicated by symbols.

d. *Aeronautical.* Aeronautical features such as airports, airways, navigation radio facilities, etc., are shown on these charts. Printed near each airport is certain information concerning that airport.

e. *Area Charts.* There are 37 charts, printed back to back, covering the United States. Each is designated by name and series (e.g., New Orleans—Sectional Aeronautical Chart). Each chart covers an area containing approximately 4° of latitude and from 6° to 8° of longitude. Overlapping coverage on adjoining charts will be provided on the north and east sides to facilitate transition between charts. Charts are printed to the edge of the sheet, eliminating the need for cutting and folding of border areas when matching data on adjacent charts is required.

f. *Fold.* Each chart will be folded to convenient dimensions of 5 x 10 5/16 inches to provide for easy handling and stowage. The unique fold is designed to provide rapid switchover from front to back, insuring availability of navigation information for continuous and uninterrupted flight.

8-11. WORLD AERONAUTICAL CHART

The world aeronautical chart (scale 1:1,000,000) is published by the National Ocean Survey, National Oceanic and

Atmospheric Administration, United States Department of Commerce. There is no Department of Defense (DOD) requirement for civil editions of domestic WACs. DOD requirements are being met by operational navigation charts (ONC).

[redacted]

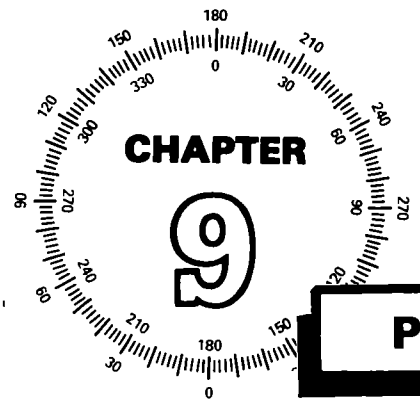
Photomaps prepared by the Army Map Service, Corps of Engineers, are used for air navigation over small areas. These maps may be constructed by using a single photomap or a mosiac of several photomaps. They may be printed on the reverse side of tactical maps. The scales are 1:25,000, 1:50,000, and 1:100,000. Meridians and parallels are indicated on the margin of the map. Positions are located by reference to a system of horizontal and vertical grid lines.

[redacted]

These charts are produced to satisfy most DOD requirements for 1:500,000-scale charts of the United States. They are used for detailed preflight planning; mission analysis; low-to-medium altitude navigation; and low level, high speed navigation. Sectional charts of comparable coverage are produced by the National Ocean Survey (para 8-10) to satisfy civil needs. There is a recognized US Army requirement for the civil edition for use in low level visual pilotage.

[redacted]

These charts use the Lambert conformal projection with a scale of 1:1,000,000. They are designed primarily for preflight planning and medium altitude enroute navigation by dead reckoning; visual pilotage; and celestial, radar, and other electronic techniques. These charts replace world aeronautical charts in areas of duplicate coverage.



PLOTTING AND MEASURING

9-1 GENERAL

Plotting is establishing points and lines on a chart with reference to meridians and parallels. *Measuring,* as used in this chapter, refers to the measurement of distance and direction on a chart. The chart serves as a record of the flight and provides information necessary for the successful completion of the flight. Chart work is a fundamental navigation skill and must be accurate.

9-2 PLOTTING TOOLS

a. *Pencil and Eraser.* Use a sharp, soft lead pencil and a soft eraser. The pencil makes a fine black line which is easy to see and makes chart work more precise; the eraser will not damage the chart.

b. *Dividers.* Use dividers to step off distances on a chart. The dividers should have their points separated to the desired distance as determined from the proper chart scale (latitude or graphic) or the plotter scale (fig 9-1). The distance scale is thereby transferred to the working area of the chart and lines of desired length can be properly marked off. By reversing the process, unknown distances on the chart can be spanned with the dividers and compared with the chart scale. While measurements are being made, the charts must be flat and smooth between the dividers. A wrinkle may cause an error of several miles.

c. *Plotter.* A plotter is an instrument designed primarily to aid in drawing and measuring lines on an aeronautical chart. The plotter, air navigation, type PLU-2/C, is the type currently in use by the Army aviator.

9-3. DESCRIPTION OF THE TYPE PLU-2/C PLOTTER

a. *General.* The PLU-2/C plotter (fig 9-1) is made of transparent plastic and has lines and scales printed in black. The rectangular part of the plotter has a straightedge for drawing lines, and scales for measuring distances. The semicircular part of the plotter has three circular scales for measuring direction.

b. *Rectangular Part.* All scales on the rectangular part are for measuring distances in nautical miles. The two upper scales read outward from the center in both directions. The three lower scales read from left to right. Scales of 1:500,000 (Sectional Aeronautical Charts), 1:100,000 (Operational Navigation Charts and World Aeronautical Charts), and 1:2,000,000 (charts such as Jet Navigation Charts) are provided.

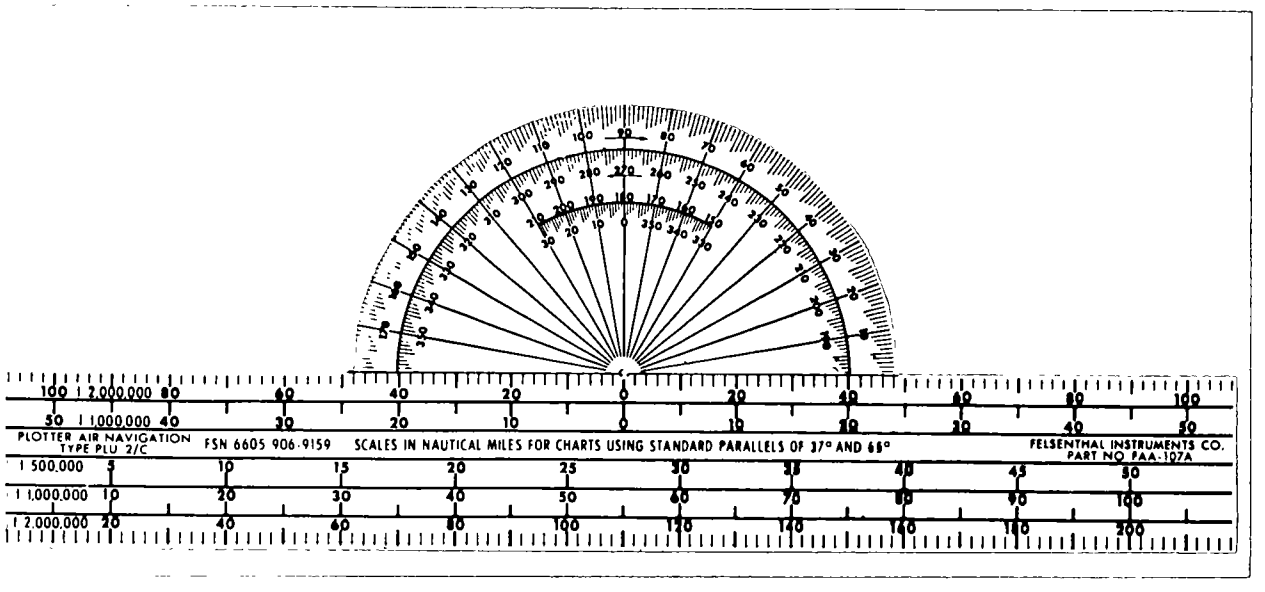


Figure 9-1. Plotter, air navigation, type PLU-2/C.

c. *Circular Scales.* The circular scales are calibrated in degrees. The outer scale, reading from 0° to 180° (right to left), is for direction in the first and second chart quadrants (north through east to south, fig 9-2). Since these directions are to the right on the chart, the outer scale has an arrow pointing to the right. The inner scale, reading from 180° to 360° (right to left), is for directions in the third and fourth quadrants (fig 9-3). The center of curvature of both scales is marked by a small hole.

d. *The 60° Center Scale.* This scale is an aid when measuring courses that are nearly north or south. The outer scale reads from 150° to 210° and the inner scale reads from 30° to 330°.

9-4. TECHNIQUE FOR USING THE PLU-2/C PLOTTER

a. *Measuring a Course.* To measure a course (fig 9-4), place the center hole on a

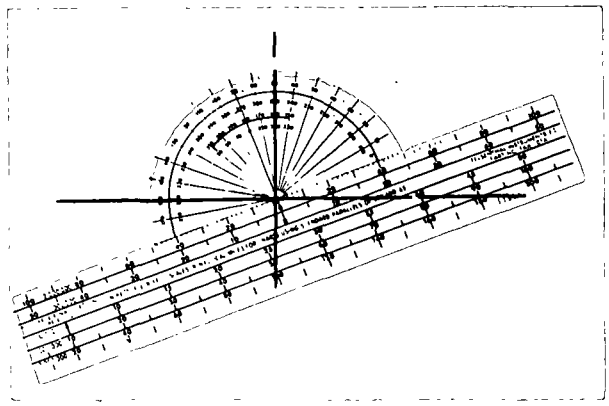


Figure 9-2. Measuring course in the first and second quadrants.

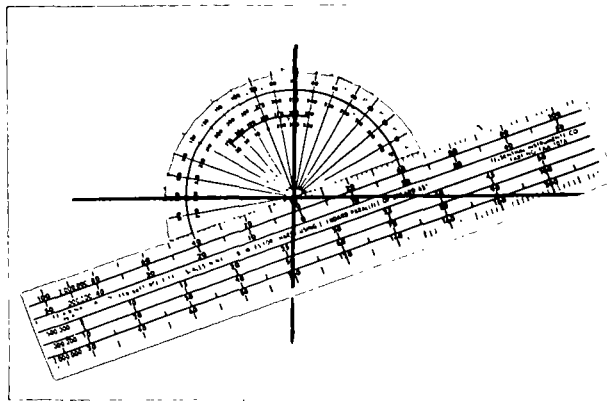


Figure 9-3. Measuring course in the third and fourth quadrants.

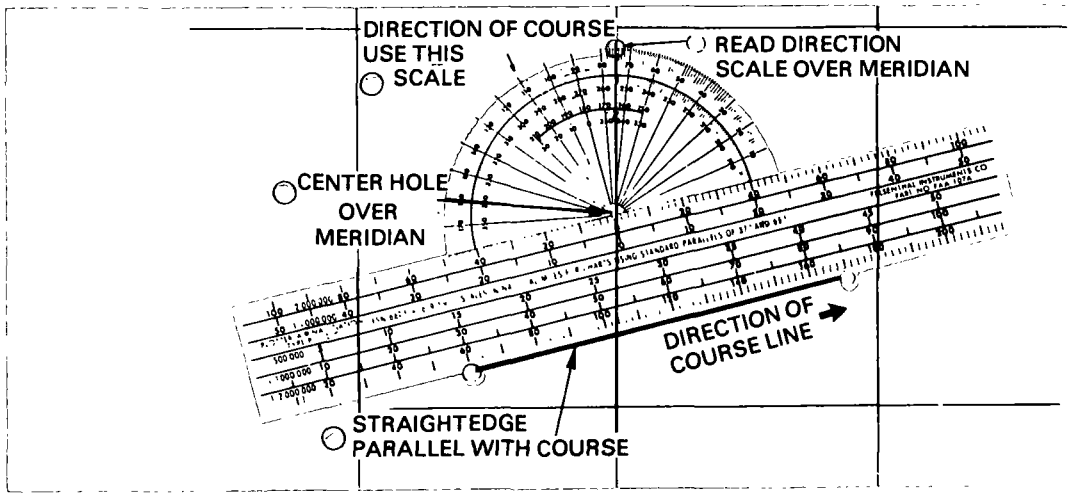


Figure 9-4. Measuring course.

meridian approximately midway along the plotted course line, and place the straightedge parallel with the course line. If the chart meridians do not intersect the course line, extend the line and move the straightedge of the plotter parallel to the course line until the center hole lies over a meridian (fig 9-5). Figure 9-4 shows the method of reading direction. Observe the small arrows on the circular scale to determine correct direction. Read the scale on which the small black arrow points in the direction of the course, and always read "up" the scale from the smaller values toward the larger values.

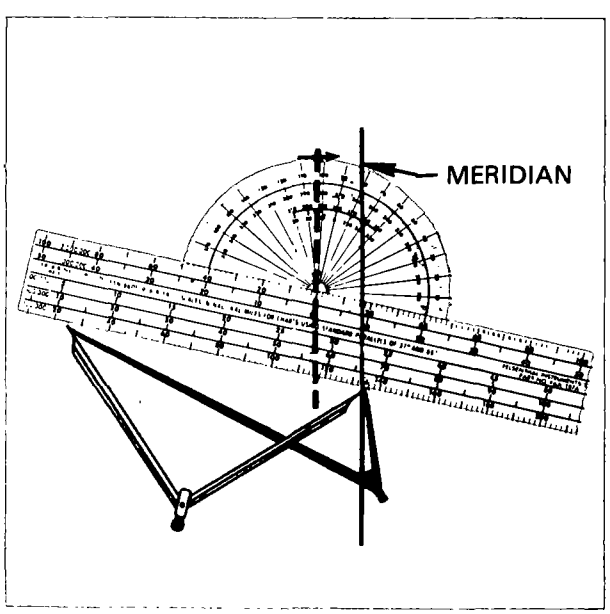


Figure 9-5. Moving plotter to a meridian.

b. *Drawing Course Line From a Known Point.* To draw a given course line from a known point, place the point-end of a pencil at the known point. While the plotter is being pushed and pivoted against the pencil, the straightedge will remain on the known point while the center hole and the scale reading are being alined with a meridian. The pencil will be in place for drawing the course line when the plotter has been properly alined with a meridian (fig 9-6).

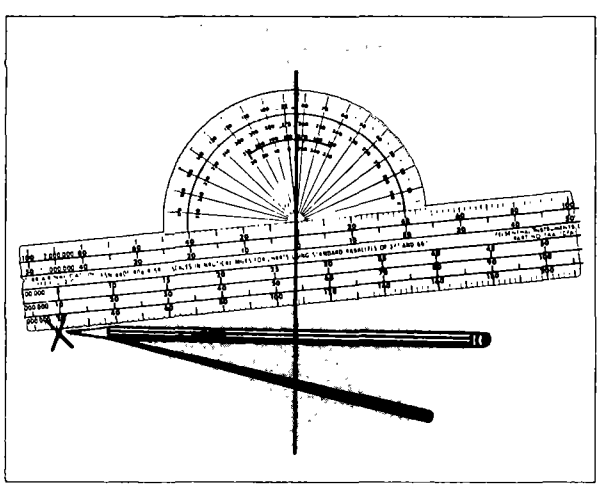
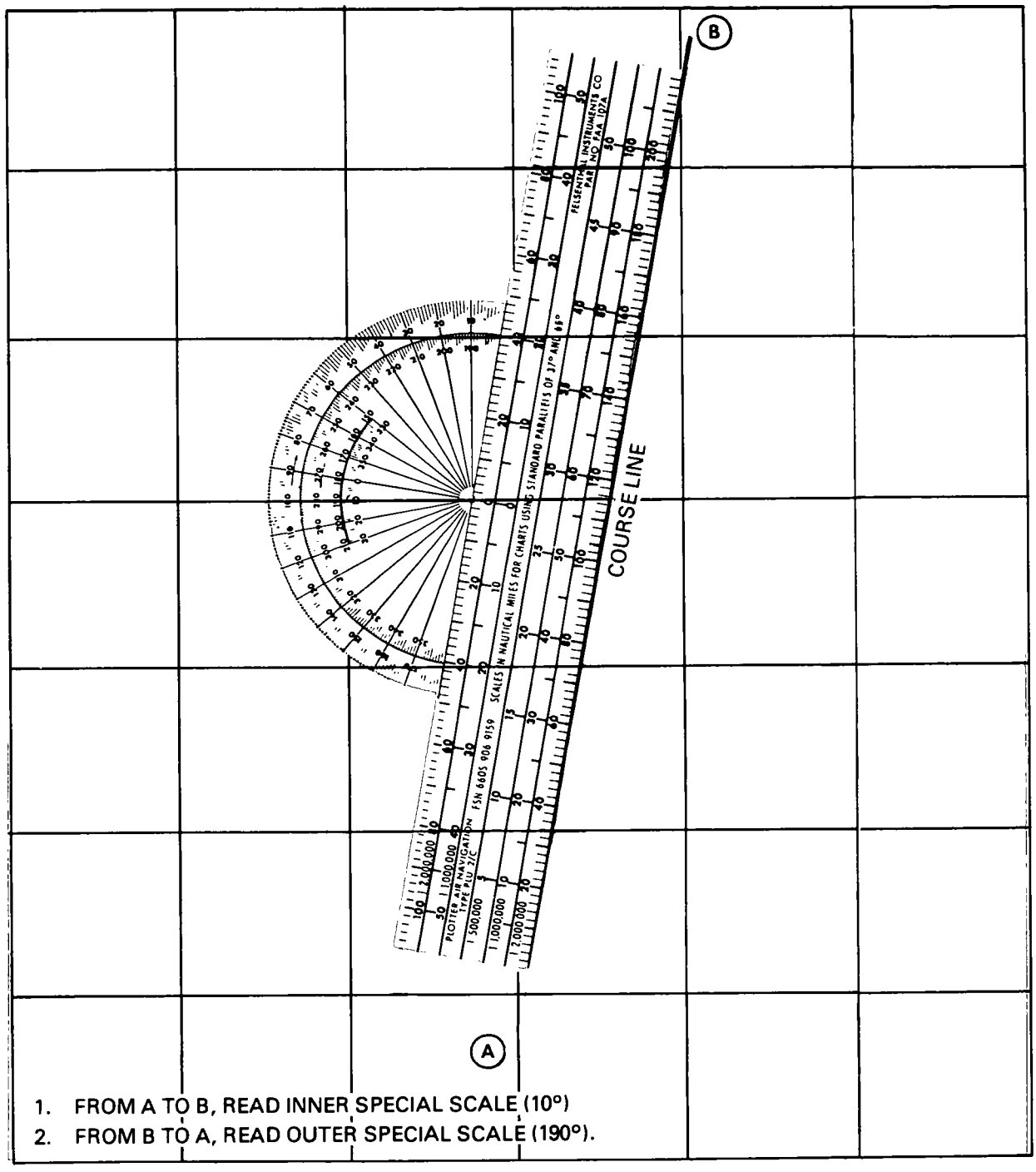


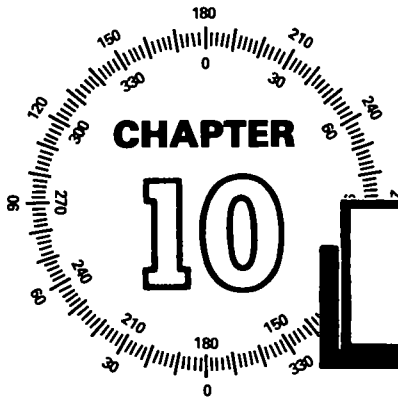
Figure 9-6. Drawing a course line from a known point.

c. *Measuring and Drawing Courses Near 0° or 180°.* In drawing a course line that is nearly north or south, the center scale may be used (fig 9-7).



NOTE: REVERSING PLOTTER POSITION FROM LEFT TO RIGHT SIDE OF THE COURSE LINE DOES NOT AFFECT READING.

Figure 9-7. Courses near 0° or 180° measured with a circular scale.



CHAPTER 10

INSTRUMENTS USED FOR DEAD-RECKONING NAVIGATION

a. *Dead-reckoning* is the method for determining position by means of a heading indicator and calculations based on speed, time elapsed, wind effect, and direction flown from a known position.

b. The instruments used by the pilot-navigator for dead-reckoning navigation include the outside air temperature gage, airspeed indicator, altimeter, clock, and one or both of the following compass systems:

(1) *Magnetic compass system.*

(2) *Slaved gyro system.*

c. These instruments provide information concerning direction, airspeed, altitude, and time, each of which must be correctly interpreted for successful navigation. Information on the instruments discussed in this chapter is general in nature. For complete description, theory, and operation of these instruments, see chapter 2 and appropriate aircraft operator's manual.

10-2. MAGNETIC COMPASS

a. *General.* Errors of the magnetic compass were discussed in chapter 2. Certain of these errors must be corrected when the compass is used for navigation.

b. *Compass Corrections, Application.*

(1) *System for applying compass corrections.* To find what the compass should read in order to follow a given course, it is corrected for drift, variation, and deviation. When drift correction (para 11-3) is applied to a true course (TC $\pm$ DC = TH), it becomes a true heading. A good method for recording application of variation and deviation is as follows:

(a) Write the following equations:

TH $\pm$ V = MH

MH $\pm$ D = CH

TH is true heading; V, variation; MH, magnetic heading; D, deviation; and CH, compass heading.

(b) Below each factor, place the known information.

TH $\pm$ V = MH

168° 12° E

MH $\pm$ D = CH

5° W

(c) When making calculations from a true heading to a compass heading, easterly error is subtracted; westerly error is added. Completing the problem, subtraction of the 12° E (variation) from the TH (168°) gives a magnetic heading (MH) of 156°. Place this figure under both of the MHs. Adding the 5° W (deviation) to the MH (156°) gives a compass heading (CH) of 161°. Place the compass heading under CH.

(2) *Reversing the equation.* To find the true heading when the compass heading is known, the same equation is written as in the above problem.

Placing the known information in the proper places, it would appear as follows:

TH $\pm$ V = MH

12° E

MH $\pm$ D = CH

5° W 161°

(a) When changing from a compass heading to a true heading, easterly error is added; westerly error is subtracted. This is the reverse of changing from TH to CH.

(b) Subtract the 5° W from the CH (161°). Place this figure (156°) below the MHs.

(c) Add the 12° E to the MH (156°) to obtain the TH (168°). Place this figure below the TH.

10-3. GYRO HEADING INDICATOR

The gyro heading indicator is used for making turns to headings and for flying headings in order to maintain a course. It is not a direction-seeking instrument and must be used in conjunction with the magnetic compass. During flight, the gyro heading indicator must be set to the same heading as the magnetic compass.

10-4. SLAVED GYRO SYSTEM

The slaved gyro system is a direction-seeking system and its heading indicator is used for making turns to headings and for flying headings in order to maintain a course. It has no significant amount of deviation and has no deviation card. Therefore, if the slaved gyro heading indicator is used for navigation, the deviation is eliminated from the equations set forth in paragraph 10-2.

10-5. AIRSPEED INDICATOR

For dead reckoning navigation, the true airspeed must be computed. To find the true airspeed, corrections must be made to the indicated airspeed or calibrated airspeed, if applicable, for temperature and pressure altitude. True airspeed computation is discussed in chapter 12. If no other method is available, the following rule of thumb may be used: Add 2 percent of the indicated airspeed for each 1,000 feet of altitude to the indicated airspeed to arrive at an approximate true airspeed.

10-6. OUTSIDE AIR TEMPERATURE GAGE

During flight the aviator will use the temperature reading from the outside air temperature gage for computing true airspeed. Refer to chapter 14 for this computation.

10-7. ALTIMETER

The altimeter is used to determine the pressure altitude during flight. Pressure altitude is determined by setting 29.92 in the Kollsman window of the altimeter. Pressure altitude is then used in computing true airspeed. Refer to chapter 12 for this computation.

10-8. CLOCK

The clock is used in flight to determine the time required to fly a measured distance on the navigation chart. The distance is then divided by the time to determine the groundspeed of the aircraft.

CHAPTER 11

WIND AND ITS EFFECTS

11-1 WIND DIRECTION AND WINDSPEED

Wind direction is the direction *from* which the wind blows; e.g., wind blowing from the northwest is a northwest wind. *Windspeed* is the rate of wind motion without regard to direction. In the United States, windspeed is usually expressed in knots (kt). Wind velocity (W/V) includes both direction and speed of the wind. *For example*, a west wind of 25 knots is recorded as W/V 270°/25 knots. "Downwind" is movement *with* the wind; "upwind" is movement *against* the wind.

11-2 EFFECT OF WIND

a. *General.* Moving air exerts a force in the direction of its motion on any object within it. Objects that are free to move in air will move in a downwind direction at the speed of the wind. An aircraft will move with the wind as does the balloon shown in figure 11-1. In addition to its forward movement through the air, if an aircraft is flying in a 20-knot wind, it will move 20 nautical

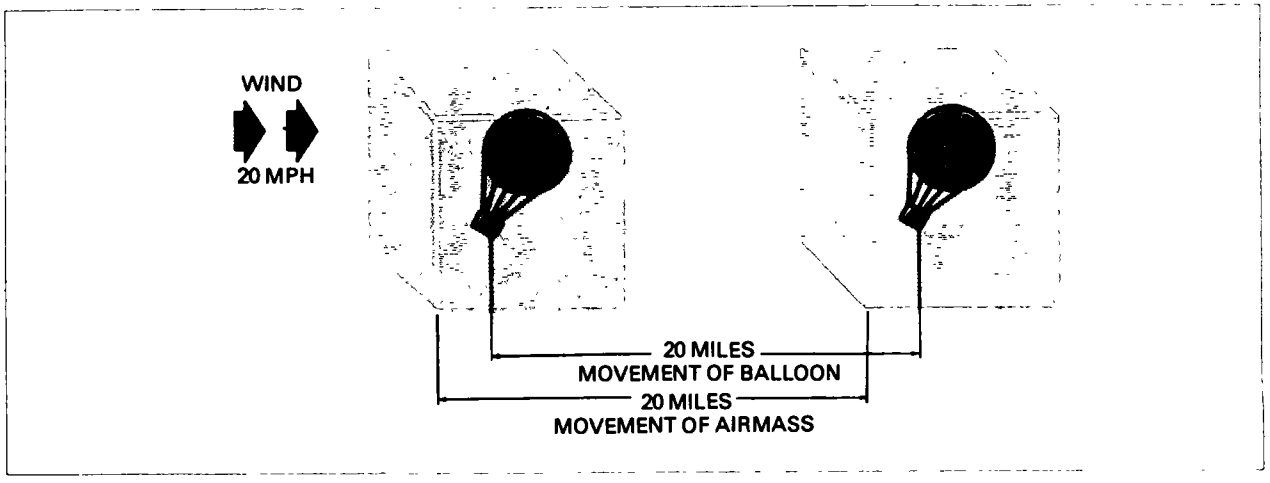


Figure 11-1. Wind effect on a free balloon in 1 hour.

miles downwind in 1 hour. The path of the aircraft *over the Earth* is determined by the motion of the aircraft through the air and the motion of the air over the Earth's surface. The direction and movement of an aircraft through the air is governed by the direction in which the nose of the aircraft is pointed and by the speed of the aircraft (fig 11-2).

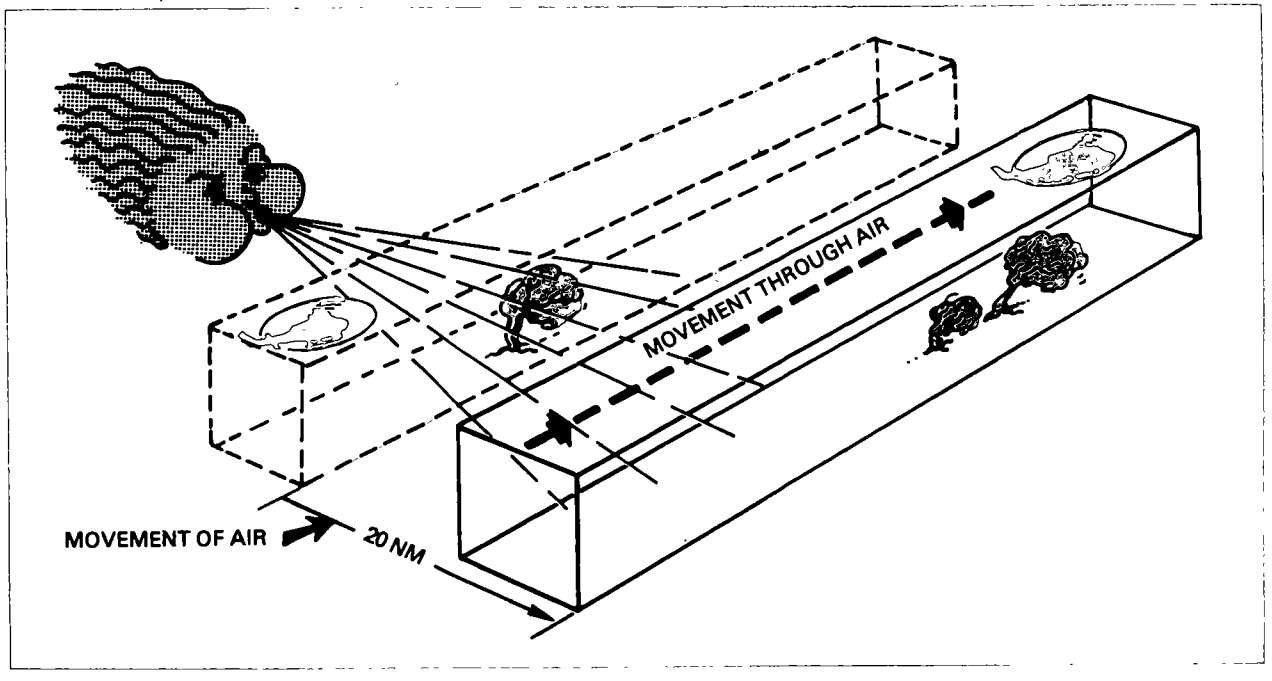


Figure 11-2. Wind effect on an aircraft.

b. *Drift.* The sideward displacement of the aircraft caused by the wind is called *drift* (fig 11-3). Drift is measured by the angle between the *heading* (direction in which the nose is pointed) and the *track* (actual path the aircraft has made over the Earth).

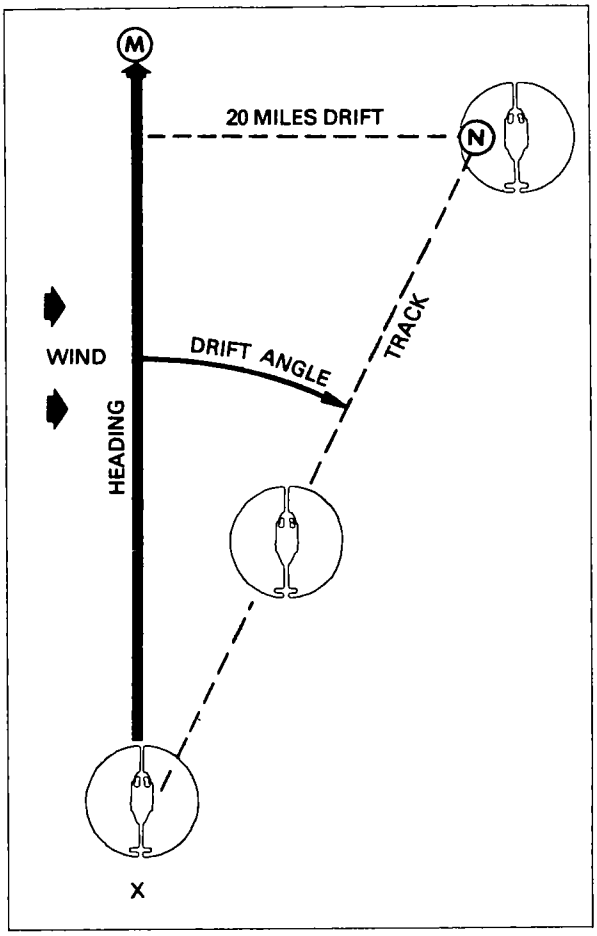


Figure 11-3. Drift.

Note: **Track must not be confused with** *course,* **which is the plotted course or intended track.**

c. *Example of Drift.* As shown in figure 11-3, an aircraft departs point X on a heading of 360° and flies for 1 hour in a wind of 270°/20 knots. The aircraft is headed toward point M directly north of X. Its heading is represented by line XM. Under no-wind conditions, the aircraft would be at point M at the end of 1 hour. However, in this example there is a wind of 20 knots and the aircraft moves with it. At the end of 1 hour, the aircraft is at point N, 20 nautical miles downwind from M. The line XM is the intended path of the aircraft through the air; the line MN shows the motion of the body of air; and the line XN is the actual path of the aircraft over the Earth.

d. *Drift and Groundspeed (GS) Change With Heading Change.* A given wind causes a different drift on each aircraft heading and affects the distance traveled over the ground in a given time. With a given wind, the groundspeed varies with each different aircraft heading.

e. *Effects of a Given Wind on Track and Groundspeed With Different Aircraft Heading.* Figure 11-4 illustrates how a

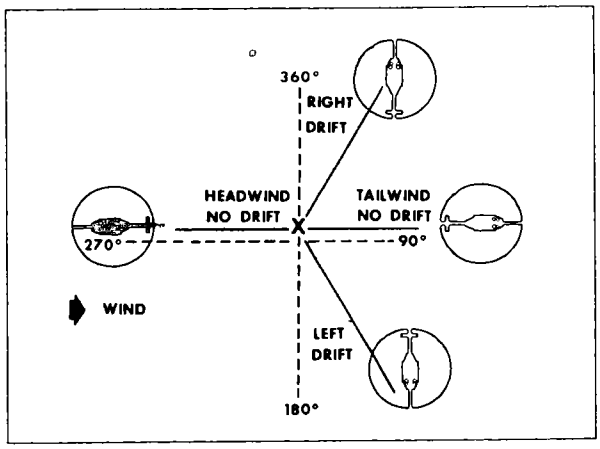


Figure 11-4. Effects of a given wind on track and groundspeed with aircraft flying on different headings.

wind of 270°/20 knots affects the groundspeed and track of an aircraft flying on headings of 360°, 090°, 180°, and 270°. On each different heading, the aircraft flies from point X for 1 hour at a constant true airspeed. The length of each dash line represents the distance the aircraft travels through the body of air. This is the same distance it would have traveled over the ground in 1 hour had there been no wind. Each solid line represents the track of the aircraft. The *length* of each solid line represents groundspeed. Differences between the length and direction of the solid and dash lines represent the wind effect on track and groundspeed.

f. *Headwind, Tailwind, and Crosswind Effect.* As shown in figure 11-4, the wind of 270°/20 knots causes right drift on a heading of 360°; on a heading of 180°, it causes left drift. On the heading of 090°, the aircraft, aided by a tailwind, travels farther in 1 hour than it would with no wind; thus, its groundspeed is increased by the wind. On the heading of 270°, the headwind reduces the groundspeed. On a heading of 360°, and 180°, the groundspeed effect is usually complicated by the drift correction applied.

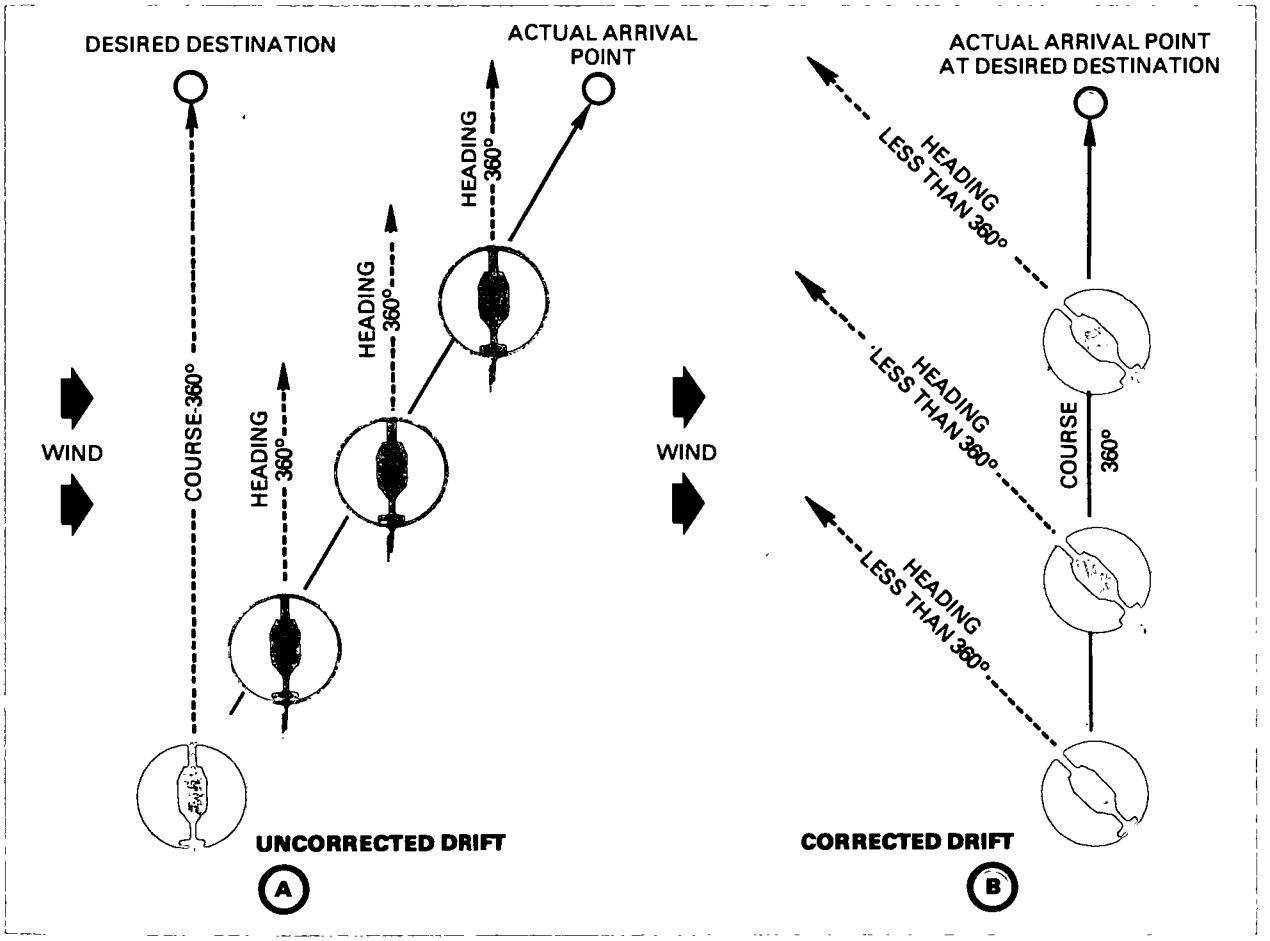


Figure 11-5. Drift and drift correction.

11-3. DRIFT CORRECTION

Drift correction must be applied to a course to determine the heading. The amount of drift correction must be just enough to compensate for the amount of drift on a given heading. The drift correction angle (DCA) (sometimes called *crab angle*) is equal to, but in the opposite direction from, the drift angle (DA). If an aviator attempts to fly to a destination due north of his point of departure on a heading of 360° and a west wind is blowing, he will arrive somewhere east of his destination because of right drift ((A), fig 11-5). To correct for right drift so that the aircraft will remain on course and arrive at the desired destination, the nose will have to be pointed to the *left* of the course, or upwind ((B), fig 11-5).

11-4. SUMMARY OF DRIFT AND DRIFT CORRECTION

a. Wind from the right causes drift to the left.

b. Wind from the left causes drift to the right.

c. If heading is greater than track or course, drift is to the left.

d. If heading is less than track or course, drift is to the right.

e. If drift is to the right, drift correction is to the left.

f. If drift is to the left, drift correction is to the right.

g. Drift is always downwind.

h. Drift correction is always upwind.

11-5. APPLIED PROBLEMS OF DRIFT AND DRIFT CORRECTIONS

a. *Problem.* Heading 160°, track 170°. Is drift right or left? Is drift correction to be made to right or left?

Solution. Since heading is less than track, drift is right; drift correction is left.

b. *Problem.* Heading 350°, drift 4° left. What is the track? What is the drift correction?

Solution. Since drift is left, heading must be greater than track. Track equals 346° (350° - 4°).

Drift correction 4° right.

c. *Problem.* Track 005°, drift 10° right. What is the heading? What drift correction is required?

Solution. Since drift is right, heading is less than track.

Heading equals 355° (005° - 10° or 365° - 10°).

Drift correction equals 10° left.

[redacted]

Groundspeed is the result of wind velocity and the forward motion of the aircraft through the air. In calm air, the speed of the aircraft over the ground is equal to its true airspeed (TAS). If the aircraft is moving against the wind (headwind), the groundspeed is equal to the difference between the true airspeed and the windspeed. If the aircraft is moving with the wind (tailwind), the groundspeed is equal to the sum of the true airspeed and the windspeed. If the aircraft is moving at an angle to the wind, the groundspeed may be any speed between the extremes of the groundspeeds determined by headwinds and tailwinds. Those groundspeeds that are less than the true airspeed are the result of hindering winds; those greater than the true airspeed are the result of helping winds. Wind directions that are approximately 90° to the longitudinal axis of the aircraft (abeam winds) have a minimum effect on groundspeed. Winds may be classified as *headwinds* (hindering winds), *tailwinds* (helping winds), and *crosswinds* (quartering headwinds or quartering tailwinds).

[redacted]

Average groundspeed is calculated by dividing the total distance flown by the total time (in hours) required for the flight. Airspeed factors to be considered in computing average groundspeed include—

a. Climbing airspeed is usually less than cruising airspeed.

b. Flying a constant true airspeed on the same outbound and return course with a constant wind velocity does not produce an average groundspeed equal to the average TAS. *For example,* figure 13-6 illustrates an aircraft flying a constant TAS (100 kt) for 1 hour against a 30-knot headwind and returning to the starting point.

(1) The aircraft will traverse 70 nautical miles (NM) in 1 hour on the outbound course ((A), fig 11-6); groundspeed is 70 knots (100 kt TAS - 30 kt W/V).

(2) On the return course ((B), fig 11-6), the aircraft will have a groundspeed of 130 knots (100 TAS + 30 W/V) and will traverse the 70-nautical-mile distance in 32 minutes (0.53 hour).

(3) The total distance (140 NM) divided by the total flying time (1.53 hours) equals an average groundspeed of 91 knots.

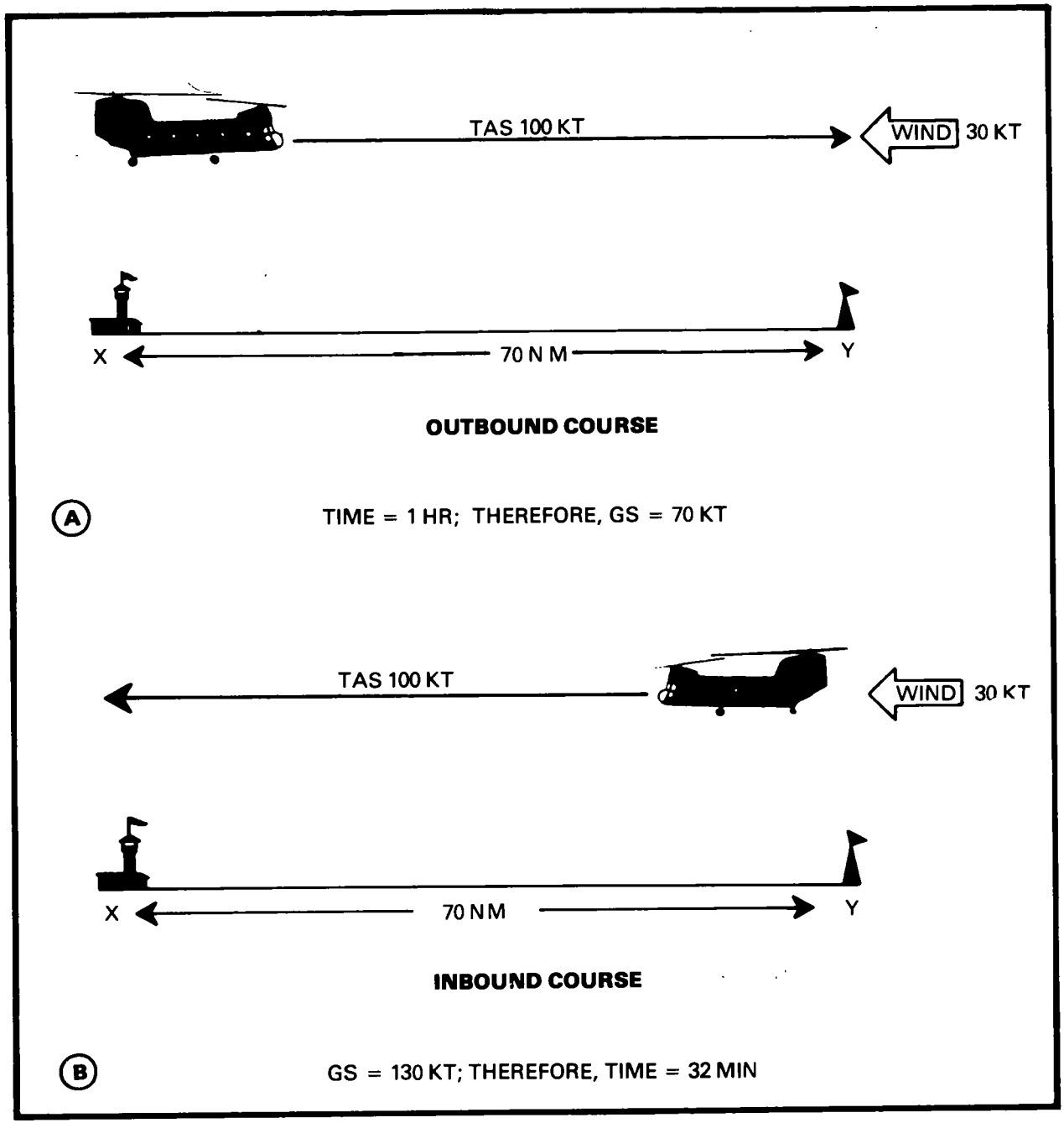
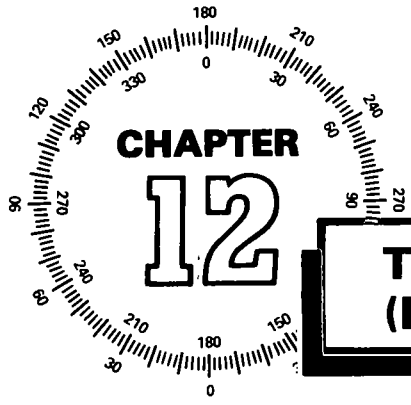


Figure 11-6. Average groundspeed.



CHAPTER 12

THE DEAD-RECKONING (DR) COMPUTER

Section I. GENERAL

12-1. CONSTRUCTION AND PURPOSE

A dead-reckoning computer is a combination of two devices, one a specially designed instrument for solving wind triangles and the other a circular slide rule for solving mathematical problems.

12-2. THE CPU-26A/P DR COMPUTER

Many different types of dead-reckoning navigation computers exist, but the construction and design features of the major types are very similar. For illustrative purposes, the standard Army DR computer, type CPU-26A/P, is used throughout this chapter.

Section II. THE SLIDE RULE FACE

12-3. THE SLIDE RULE

a. *Scales.* The slide rule of the CPU-26A/P computer consists of two circular scales. The outer scale is stationary and is called the *miles* scale. The inner scale rotates and is called the *minutes* scale.

b. *Scale Values.* The numbers on any computer scale, as on most slide rules, represent multiples of 10 of the values shown. *For example,* the number 24 on either scale (outer or inner) may represent 0.24, 2.4, 24, 240, or 2,400. On the inner scale, minutes may be converted to hours by reference to the adjacent hour scale. For example, 4 hours is found in figure 12-1 adjacent to 24; in this case, meaning 240 minutes. Relative values should be kept in mind when reading the computer. *For example,* the numbers 21 and 22 on either scale are separated by five spaces, each space representing two units. The second division past 21 will be read as 21.4, 2,140, etc. Spacing of these divisions should be studied, as the breakdown of dividing lines may be into units of 1, 2, 5, or 10.

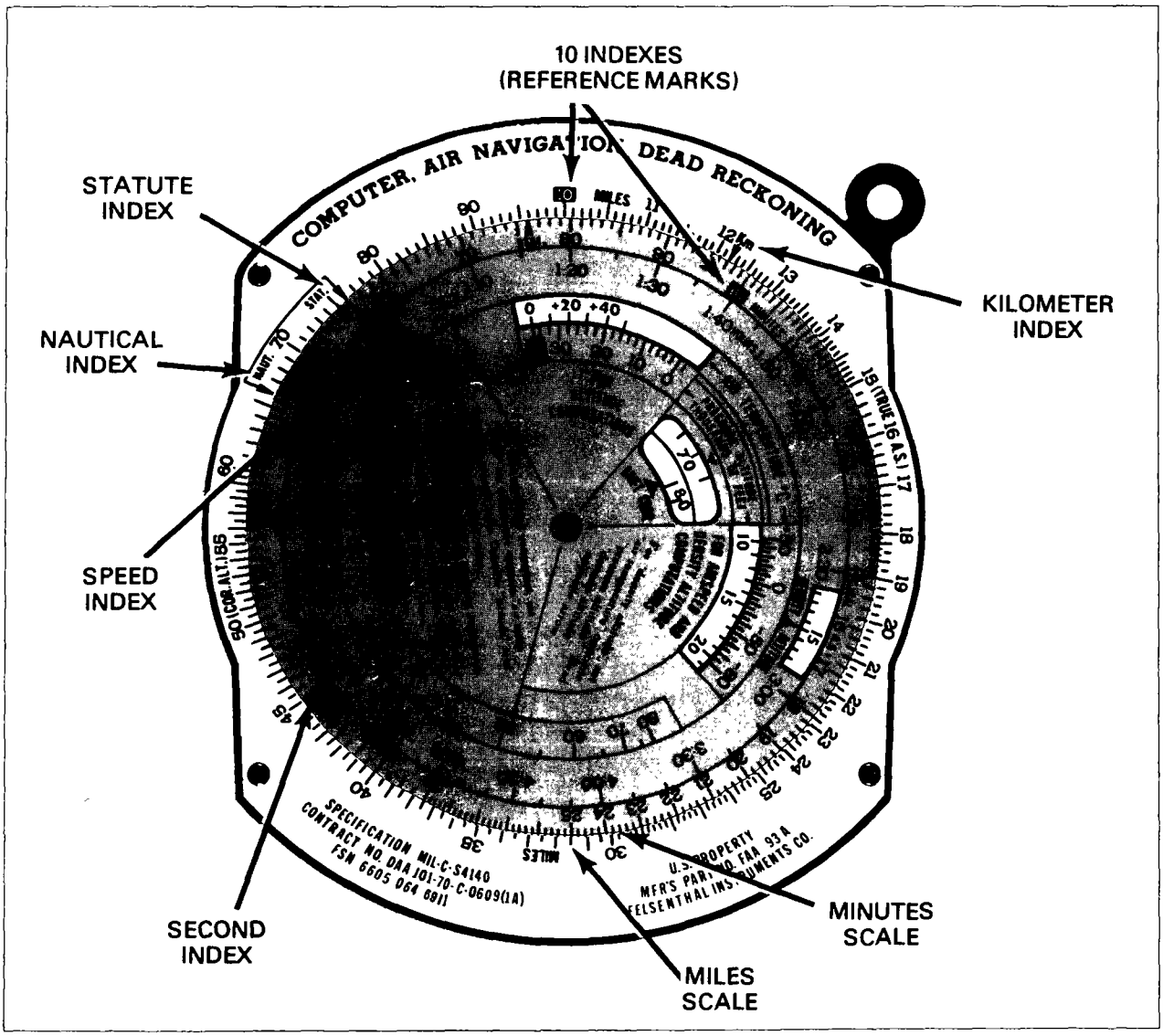


Figure 12-1. Slide rule face.

c. *Indexes.* Three of the indexes on the outer stationary scale are used for converting statute miles, nautical miles (NM), and kilometers. These indexes are appropriately labeled "Naut" at 66, "Stat" at 76, and "Km" at 122. On the inner rotating scale are two rate indexes. The large black arrow at 60 (called the *speed* index) is the hour index, and the small arrow at 36 is the second ("Sec") index (3,600 seconds equal 1 hour). The "Stat" index on the inner scale is used in mileage conversion. Each scale has a "10" index used as a reference mark for multiplication and division. The application of these scales in solving computer problems is illustrated in the specific problems that follow.

[redacted]

a. *Problem.* How many statute miles equal 90 nautical miles? How many kilometers equal 90 nautical miles?

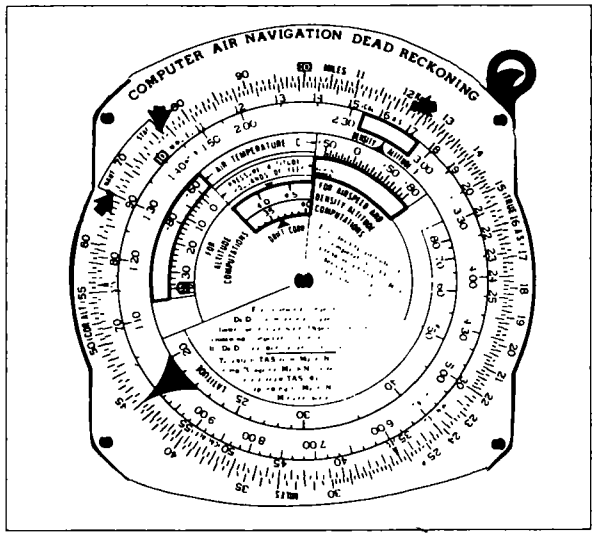


Figure 12-2. Distance conversion.

b. *Solution.* Using the DR computer, refer to figure 12-2 and solve as follows:

> *Note.* **When several distance conversion problems are to be solved between statute and nautical miles, set the "Stat" index on the inner scale under the "Naut" index of the outer scale and read any ratio around the entire slide rule; i.e., 13 statute miles is 11.3 nautical miles, 13 nautical miles is 15 statute miles, etc. (fig 12-3).**

(1) Set 90 on inner scale to "Naut" index.

(2) Read 104 under "Stat" index (104 statute miles).

(3) Read 166 under "Km" index (166 kilometers).

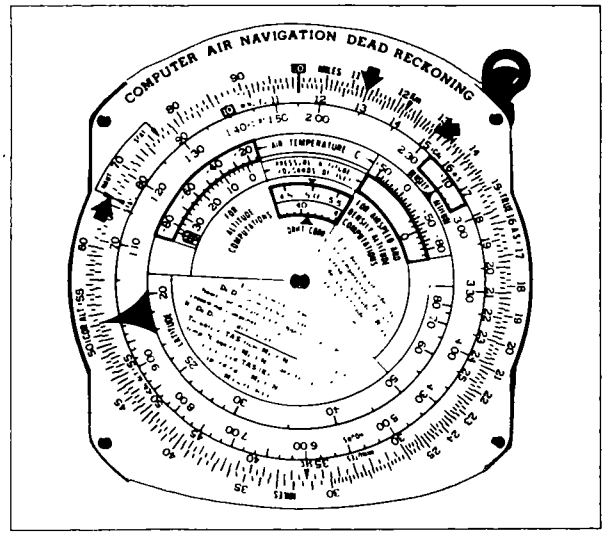


Figure 12-3. Converting several distances simultaneously.

The slide rule face of the DR computer is so constructed that any relationship between two numbers, one on the stationary scale and one on the movable scale, will hold true for all other numbers on the two scales. *For example,* if the two "10" indexes are placed opposite each other (fig 12-4), all other numbers around the entire circle will be identical. If 20 on the inner scale is placed opposite the "10" index on the outer scale, all numbers on the inner scale will be double those on the outer scale. If 12 on the outer scale is placed opposite 16 on the inner scale, all numbers will be in a 3 to 4 (3/4) relationship. This scale design enables the aviator to find the fourth term of any mathematical proportion when three of the values are known.

Time-distance problems are worked on the inner (minutes) scale and the outer (miles) scale.

a. *Problem.* If 50 minutes are required to travel 120 nautical miles, how many minutes are required to travel 86 nautical miles at the same rate?

b. *Solution.* Using the DR computer, refer to figure 12-5 and solve as follows:

(1) Set 50 (inner scale) under 120 (outer scale).

(2) Under 86 (outer scale), read 36 (inner scale) minutes required.

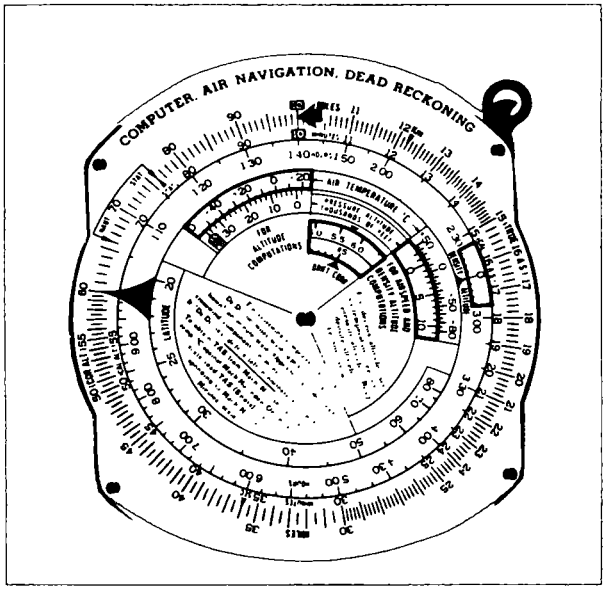


Figure 12-4. Numerical relationship between the two scales.

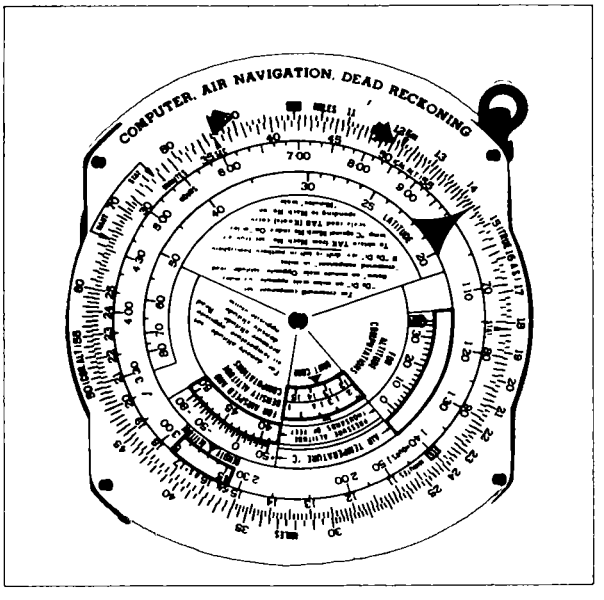


Figure 12-5. Time and distance.

12-7. DETERMINING GROUNDSPEED (GS)

Groundspeed equals distance divided by time.

a. *Problem.* What is the groundspeed if it takes 35 minutes to fly 80 nautical miles?

b. *Solution.* Using the DR computer, refer to figure 12-6 and solve as follows:

(1) Set 35 (inner scale) opposite 80 (outer scale).

(2) Over 60 index read groundspeed (137 knots (kt)).

12-8. DETERMINING TIME REQUIRED

Time equals distance divided by groundspeed.

a. *Problem.* How much time is required to fly 333 nautical miles at a groundspeed of 174 knots?

b. *Solution.* Using the DR computer, refer to figure 12-7 and solve as follows:

(1) Set 60 index on 174 (outer scale).

(2) Under 333 (outer scale) read 115 minutes (inner scale) 1 + 55 (hours scale).

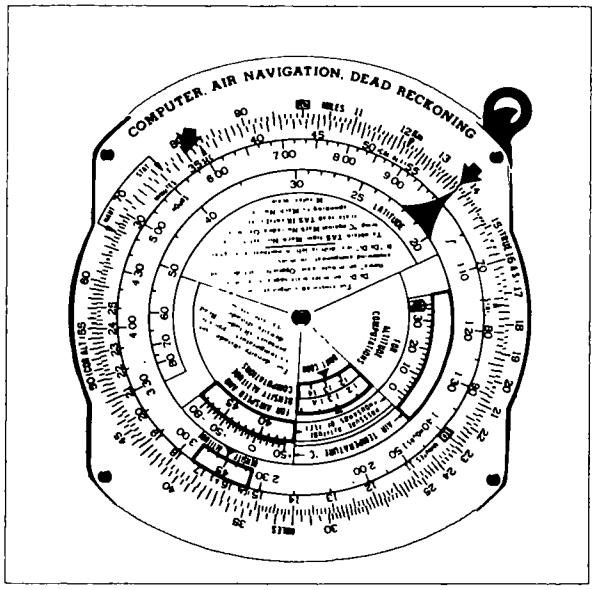


Figure 12-6. Determining groundspeed.

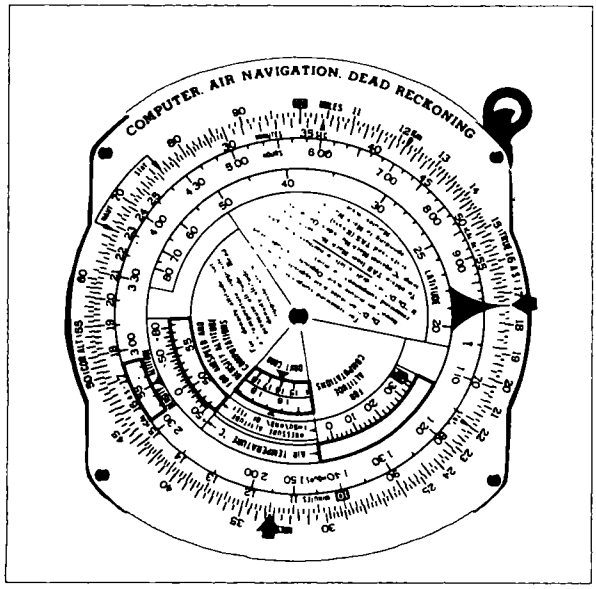


Figure 12-7. Determining time.

12-5. DETERMINING DISTANCE

Distance equals groundspeed multiplied by time.

a. *Problem.* How far does an aircraft travel in 2 hours and 15 minutes at a groundspeed of 138 knots?

b. *Solution.* Using the DR computer, refer to figure 12-8 and solve as follows:

(1) Set 60 index at 138 (outer scale).

(2) Over 135 (inner scale) or 2 hours and 15 minutes (hours scale), read 310 nautical miles (outer scale).

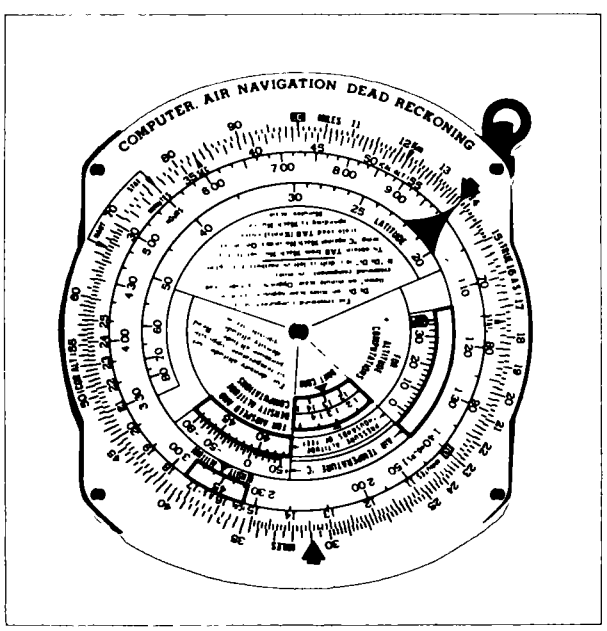


Figure 12-8. Determining distance.

The number 36 on the inner scale is used in solving rate-time-distance problems in instrument flight when time must be calculated in seconds and minutes instead of minutes and hours. *For example,* determine the time required to fly from the final approach fix (FAF) to the missed approach point on an instrument approach (chap 18).

a. *Formula.* Problems where seconds must be used as a unit of time may be solved by the formula

$$\frac{GS}{36} = \frac{\text{Distance}}{\text{Seconds}}$$

in which GS is the groundspeed; 36 represents the number of seconds in 1 hour (3,600); distance is the number of miles or decimal parts of miles to be flown; and seconds is the time required to fly that distance.

b. *Problems Involving Less than 60 Seconds.*

(1) *Problem.* What is the time required from the middle marker to the point of touchdown if the groundspeed is 100 knots and the distance between these points is 0.5 nautical mile?

(2) *Solution.* Set 36 (inner scale) under the groundspeed of 100 knots (10 on the outer scale). Under 50 (0.5 NM) on the outer scale, read 18 seconds on the inner scale (fig 12-9).

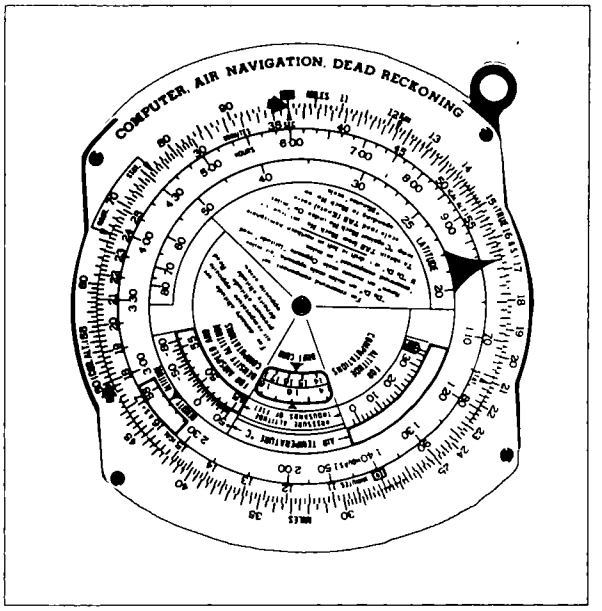


Figure 12-9. Rate-time-distance problems using minutes.

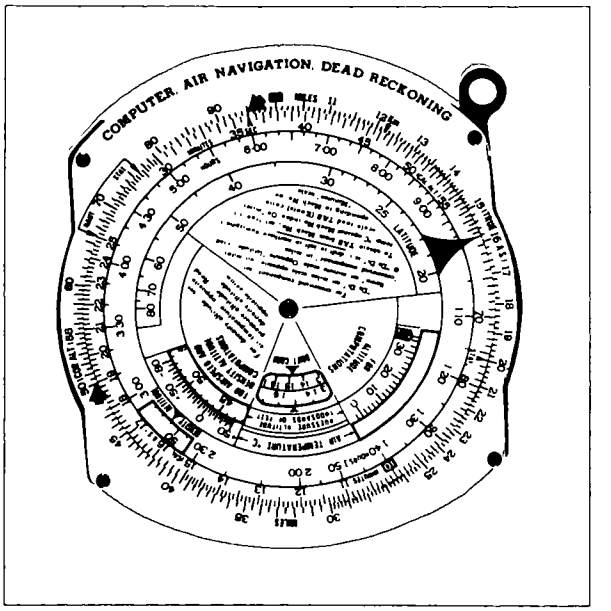


Figure 12-10. Rate-time-distance problems using seconds.

c. *Problems Involving More than 60 Seconds.*

(1) *Problem.* What is the time required to fly from the outer marker to the middle marker if the groundspeed is 95 knots and the distance between the two points is 5 nautical miles?

(2) *Solution.* Set 36 (inner scale) under the groundspeed of 95 knots (95 on the outer scale). Under 50 (5 NM) on the outer scale, read 19 (190 seconds), or 3 minutes and 10 seconds on the inner scale (fig 12-10).

Note. **When using the minutes scale as a seconds scale, the hours scale becomes a minute scale.**

12-11. DETERMINING GALLONS OR POUNDS USED IN A GIVEN TIME

Place the 60 index under rate (gallons per hour (gph)) and read gallons used over the given time. To convert gallons to pounds or pounds to gallons, the following conversion factors are used in simple proportion (para 12-5):

a. Gasoline: 6.0:1.

b. JP-4 fuel: 6.5:1.

12-12. DETERMINING RATE OF FUEL CONSUMPTION

Rate of fuel consumption equals gallons of fuel consumed divided by time.

a. *Problem.* What is the rate of fuel consumption if 30 gallons of fuel are consumed in 111 minutes (1 hour and 51 minutes)?

b. *Solution.* Using the DR computer, refer to figure 12-11 and solve as follows:

(1) Set 111 (inner scale) under 30 on outer scale (in this case, outer scale is used to represent gallons).

(2) Opposite the 60 index, read 16.2 gallons per hour.

[redacted]

Use same scales as used with the time-distance problems discussed in paragraph 12-6 and solve the following fuel consumption problem:

a. *Problem.* Forty gallons of fuel have been consumed in 135 minutes (2 hours and 15 minutes) flying time. How much longer can the aircraft continue flying if 25 gallons of available fuel (usable fuel not including reserve) remain and the rate of consumption remains unchanged?

b. *Solution.* Using the DR computer, refer to figure 12-12 and solve as follows:

(1) Set 135 (inner scale) under 40 (outer scale).

(2) Under 25 (outer scale), read 84.5 (inner scale) minutes fuel remaining.

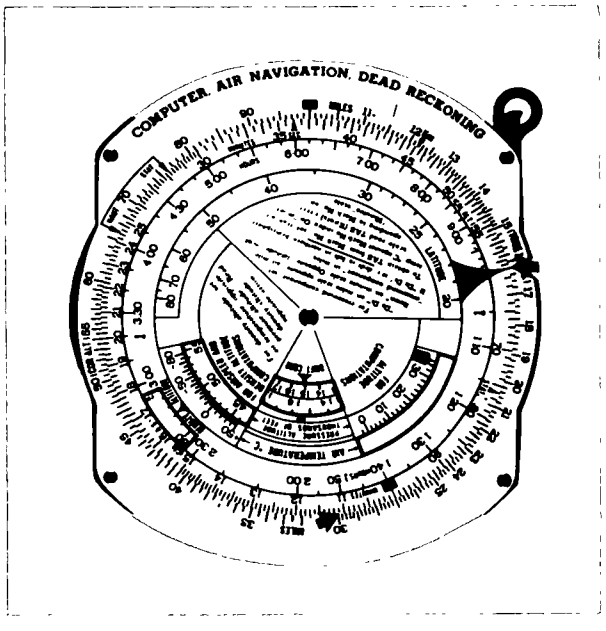


Figure 12-11. Determining rate of fuel consumption.

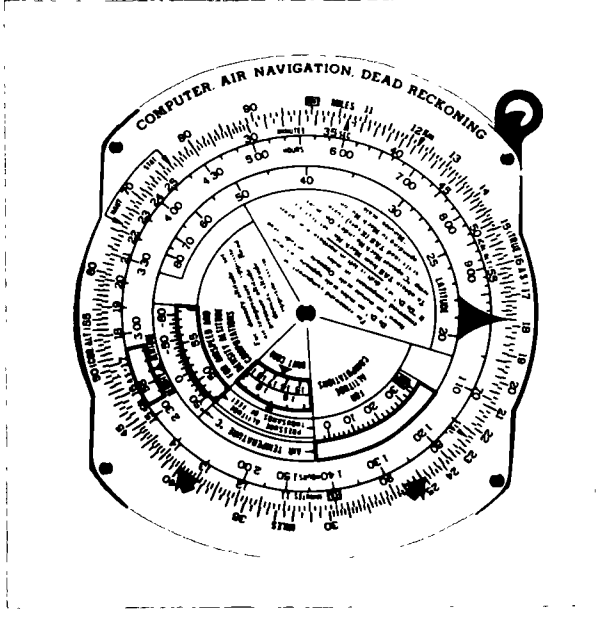


Figure 12-12. Fuel consumption.

[redacted]

Aircraft performance data charts used in determining maximum flying range sometimes base fuel consumption rates on nautical miles flown per pound or gallon of fuel consumed. The aviator often desires to compute maximum flying range based on fuel consumption rate in pounds or gallons per hour. This conversion is accomplished as follows:

a. *Formula.* The relationship between nautical miles per pound and pounds per hour is expressed as—

Nautical miles per pound (or gallon)
=
True airspeed (TAS) (miles flown per hour)
1 pound (or gallon)
Pounds (or gallons) per hour

b. *Problem.* The maximum flying range based on fuel consumption is indicated on the aircraft performance chart as .231 nautical mile per pound. At a true airspeed of 196 knots, what is the aircraft fuel consumption rate in pounds per hour?

c. *Solution.* Using the DR computer, refer to figure 12-13 and solve as follows:

(1) Set .231 (nautical mile per pound) on the outer scale over the "10" index (1 pound) on the inner scale.

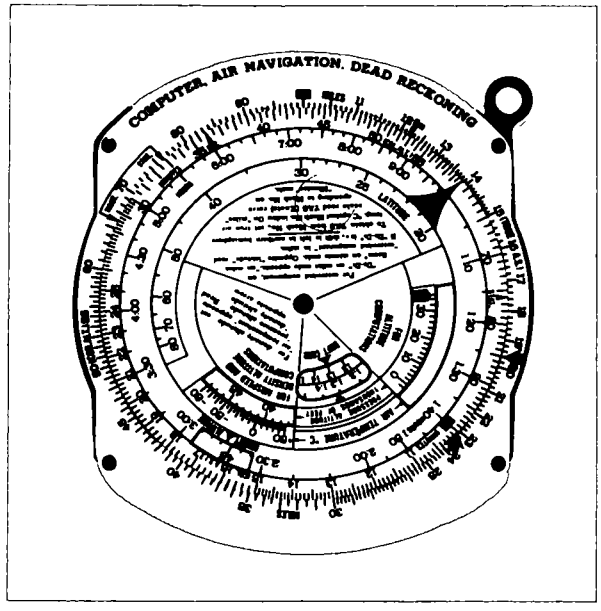


Figure 12-13. Converting nautical miles per pound to pounds per hour.

(2) Under the TAS (196 knots) on the outer scale, read pounds per hour (850) on the inner scale.

[redacted]

The window marked "FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS" provides a means for computing true airspeed when indicated airspeed (IAS), temperature, and altitude are known or vice versa. To change from one to the other, it is necessary to correct for altitude and temperature differences existing from those that are standard at sea level. Free air temperature is read from a free air thermometer and the pressure altitude is found by setting the altimeter at 29.92 inches of mercury (Hg) and reading the altimeter directly.

a. *Problem.* The indicated airspeed is 125 knots, free air temperature is -15° centigrade (C), and the pressure altitude is 8,000 feet. What is the true airspeed?

b. *Solution.* Using the DR computer, refer to figure 12-14 and solve as follows:

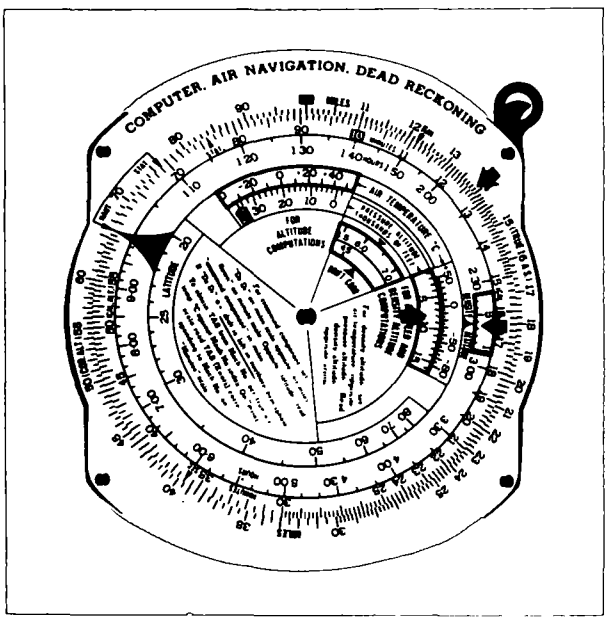


Figure 12-14. Airspeed computation.

(1) Set 8,000 against -15° C in the airspeed computation window.

(2) Over 125 knots (inner scale), read true airspeed 137 knots (outer scale).

Note. **In solving for IAS when TAS is known, locate TAS on outer scale and read answer (IAS) in inner scale.**

12-16. [illegible]

Density altitude is that altitude in the standard atmosphere at which a given air density exists. Because of variations of temperature and pressure, the density of the air on a given day at any given pressure altitude may be that density found several thousand feet higher or lower in the standard atmosphere. Such conditions can be critical in aircraft operations, especially in the operation of helicopters. To compute density altitude, rotate the movable scales of the computer so that the free air temperature is set above the pressure altitude in the window labeled "FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS." When set in this manner, the density altitude is read above the pointer in the window labeled "DENSITY ALTITUDE." Using the same flight condition as in paragraph 12-15, density altitude is read as 6,200 feet (fig 12-14). Accurate results can only be obtained by using *pressure altitude.* Pressure altitude can be read directly from the altimeter when the altimeter setting is 29.92.

12-17. [illegible]ATIONS

The window marked "FOR ALTITUDE COMPUTATIONS" provides a means for computing corrected altitude by applying any variations from standard temperature to indicated (or calibrated) altitude.

a. *problem.* The pressure altitude is 9,000 feet, indicated altitude is 9,100 feet,

and the free air temperature is -15° C. What is the corrected altitude?

b. *Solution.* Using the DR computer, refer to figure 12-15 and solve as follows:

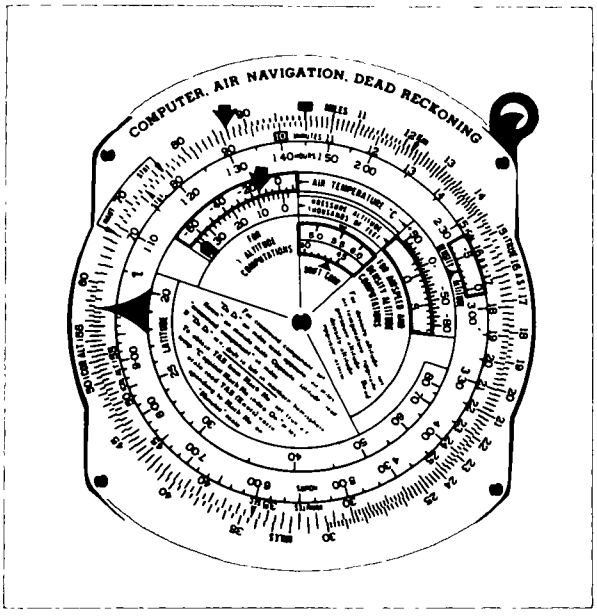


Figure 12-15. Altitude computation.

(1) Set 9,000 against -15° C in the altitude computation window.

(2) Above 9,100 feet indicated altitude (inner scale), read corrected altitude 8,700 on the outer scale (corrected altitude).

12-18. OFF-COURSE CORRECTION (RULE OF 60)

An aircraft headed 1° off course will be approximately 1 mile off course for each 60 miles flown. This is the *rule of 60.* Inversely, for each mile an aircraft is off course after each 60 miles of flight, 1° of correction will be required to *parallel* the intended course. Applied to other distances (multiples of 60), such as 1.5 miles off course in 90 miles, 2 miles off course in 120 miles, or 2.5 miles off course in 150 miles, a correction of 1° will be required to parallel the intended course. To converge at destination, an extra correction must be made based on the same rule of 60.

a. *Formulas.* The degrees correction required to converge at destination is determined by adding the results of the following formulas:

Correction to parallel course:

$$\frac{\text{MILES OFF COURSE}}{\text{MILES FLOWN}} = \frac{\text{DEGREES CORRECTION}}{60}$$

Additional correction to converge:

$$\frac{\text{MILES OFF COURSE}}{\text{MILES TO FLY}} = \frac{\text{DEGREES CORRECTION}}{60}$$

b. *Problem.* An aircraft is 10 nautical miles to the left of course when 150 nautical miles from departure point A. How many degrees correction are required to parallel course? If 80 nautical miles remain to destination B, how many additional degrees are required to converge? In what direction is the correction applied?

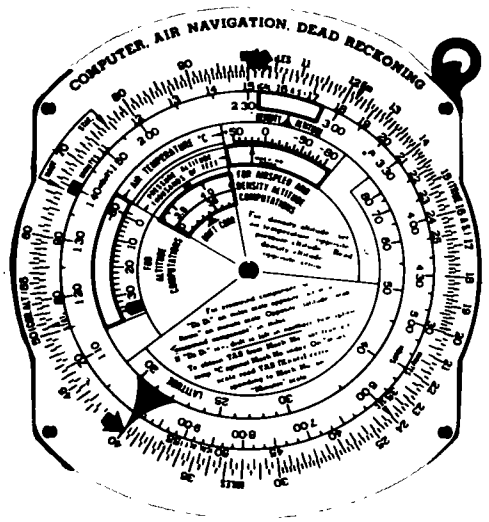


Figure 12-16. Off-course correction to parallel.

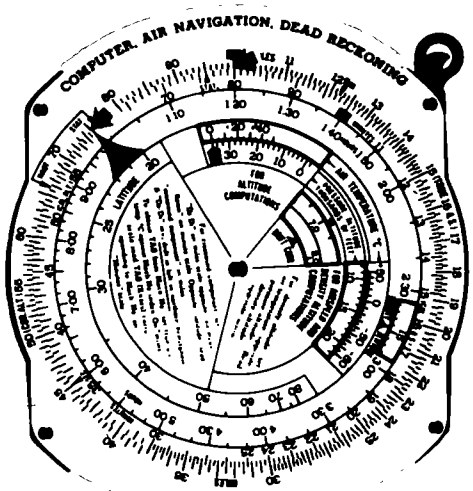


Figure 12-17. Off-course correction to converge.

c. *Solution.* Using the DR computer, refer to figures 12-16 and 12-17 and solve as follows:

(1) Set 150 (inner scale) under 10 (outer scale) (fig 12-16).

(2) Over the 60 index, read 4° (correction required to parallel).

(3) Set 80 (inner scale) under 10 (outer scale) (fig 12-17).

(4) Over 60 index, read 7.5° to converge.

(5) 4° + 7.5° = 11.5°, total correction to converge at destination. Since aircraft is off course to the left, correction will be made to the right or added to the original heading. *For example,* if the original heading were 090°, the new heading would be 101.5° or 102° to the nearest degree.

12-19. OFF-COURSE CORRECTION (DRIFT CORRECTION WINDOW)

This scale in the drift correction window of the CPU-26A/P computer is a refinement of the rule of 60 (para 12-18). Actually an arc of 1 mile subtends an angle of 1° at a distance of 57.3 miles rather than 60 miles. The drift correction window scale incorporates this relationship correctly.

a. *Problem.* After traveling 400 miles, and the aircraft is 30 miles off course—

(1) What drift correction angle is necessary to parallel the desired course?

(2) What drift correction angle is necessary to intercept the desired course in 150 additional miles?

b. *Solution.*

(1) Set the miles off course (30) on the outer scale over the distance traveled (400) on the inner scale and read the correction angle to parallel the desired course in the drift correction window (4.3°) (fig 12-18).

Note. **The drift correction window, together with the D_2-D_1 data and the latitude scale on the face of the computer, is also used in pressure pattern flying. Since the Army does not use this navigation technique, it is not explained herein.**

(2) To find the angle to intercept the desired course, place the miles off course (30) on the outer scale over the course miles to interception point (150) on the inner scale. Read the additional angle to intercept in the drift correction window (11.3°) (fig 12-19). The total correction angle to intercept the desired course is therefore 15.6° (4.3 + 11.3).

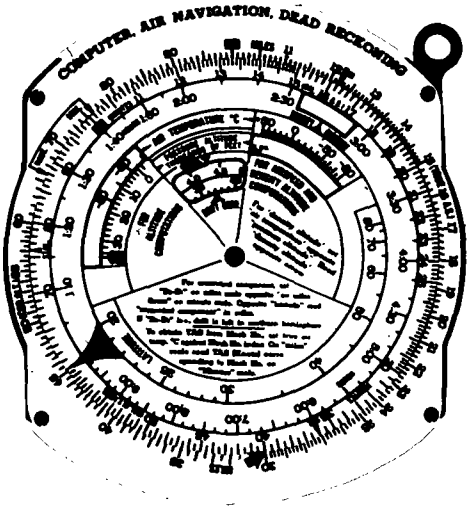


Figure 12-18. Drift correction computation to parallel.

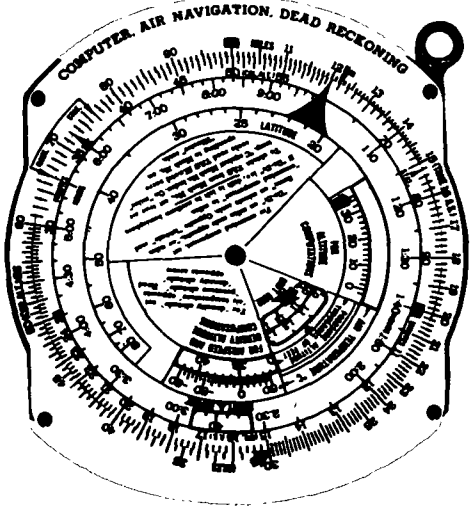


Figure 12-19. Drift correction computation to converge.

12-20. RADIUS OF ACTION (DR COMPUTER)

Radius of action to the same base refers to the maximum distance an aircraft can be flown on a given course and still be able to return to the starting point within a given time. The amount of available fuel (not including reserve fuel) is usually the factor determining time.

a. *Problem.* The groundspeed on the outbound leg of the flight is 160 knots; on the return leg, 130 knots. Available fuel permits 4.5 hours (270 minutes) total time for the flight. How many minutes will be available for the outbound leg of the flight? How many minutes will be required for the return leg of the flight? What is the radius of action?

b. *Solution.* The sum of the groundspeed out (GS_1) and the groundspeed on the return leg (GS_2) is to the total time in minutes (T), as the groundspeed on the return leg, (GS_2) is to the time in minutes on the outbound leg (t_1). Minutes on the outbound leg of the flight can be calculated by the formula $\frac{GS_1 + GS_2}{T} = \frac{GS_2}{t_1}$. The formula for calculating time required for the return leg of the flight $\frac{GS_1 + GS_2}{T} = \frac{GS_1}{t_2}$, is in which t_2 is the time required for the return leg of the flight. These formulas can be calculated on the DR computer as ratio and proportion problems and appear on the DR computer as they appear in mathematical form. To solve radius of action fixed base problems with the DR computer, use the problem given in "a" above, referring to figures 12-20 and 12-21, and proceed as follows:

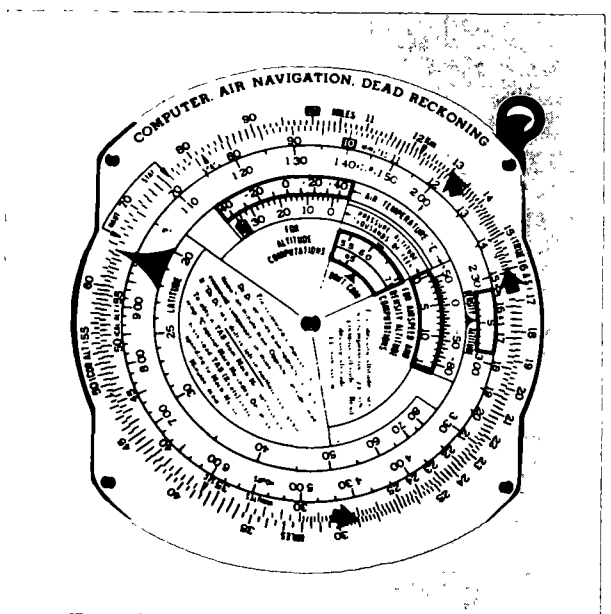


Figure 12-20. Radius of action time computation.

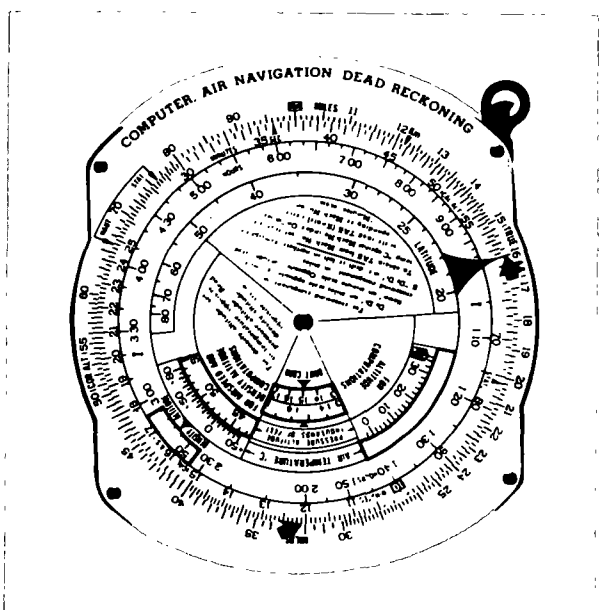


Figure 12-21. Radius of action distance computation.

(1) Find the sum of the groundspeeds (160 + 130 = 290).

(2) Set the total time (T = 4.5 hours or 270 minutes) *under* the sum of the groundspeeds (290) (fig 12-20).

(3) Under 130 (GS_2), read the time on the outbound leg, 2 hours + 1 minute or 121 minutes (fig 12-20).

(4) Without changing the setting of the computer, under 160 (GS_1), read the time required for the return leg, 2 hours + 29 minutes or 149 minutes (fig 12-20).

(5) These two amounts of time should be equivalent to the total amount of time of the flight.

(6) Place the 60 index under 160 (GS_1) and *over* 121 minutes (time on the outbound leg), read the radius of action, 322 nautical miles (fig 12-21).

Section III. GRID SIDE OF THE DR COMPUTER

12-21. PLOTTING DISK AND CORRECTION SCALES

The grid side of the DR computer (fig 12-22) enables the aviator to solve wind problems. It consists of a transparent, rotatable plotting disk mounted in a frame on the reverse side of the circular slide rule. A compass rose is located around the plotting disk. The correction scale on the top frame of the circular grid is graduated in degrees right and left of the *true index* (labeled "TRUE INDEX"). This scale is used for calculating drift or drift correction and is labeled "DRIFT RIGHT" and "DRIFT LEFT."A small reference circle, or *grommet*, is located at the center of the plotting disk.

12-22. SLIDING GRID

A reversible sliding grid (fig 12-22) inserted between the circular slide rule and

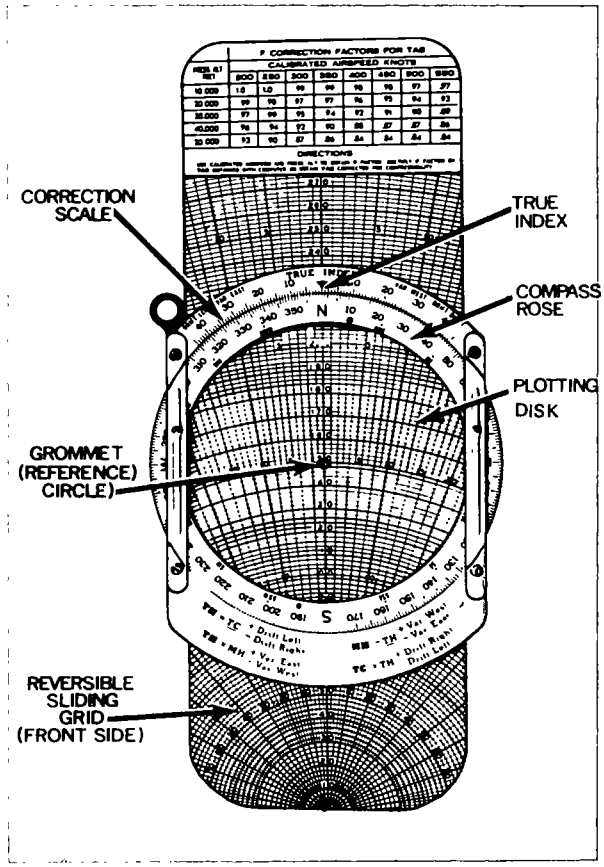


Figure 12-22. Grid side.

the plotting disk is used for wind computations. The slide has converging lines spaced 2° apart between the concentric arcs marked 0 to 150 and 1° apart above the 150 arc. The concentric arcs are used for calculations of speed and are spaced 2 units (usually knots or miles per hour) apart. Direction of the centerline coincides with the index. The common center of the concentric arcs and the point at which all converging lines meet is located at the lower end of the slide. On one side of the sliding grid, the speed arcs are scaled from 0 to 270; on the reverse side, from 70 to 800. The low range of speeds on the sliding grid is especially helpful in solving navigational problems for aircraft having slow speed flight characteristics.

a. *Rectangular Grid.* The rectangular grid on the reverse side of the sliding grid (fig 12-23) is designed so that the left half can be used for calculations on the 70 to 800 side of the sliding grid and the right half can be used with the 0 to 270 side of the sliding grid. On the left half, each small division has a value of 10 units; each large division has a value of 50 units. On the right half, the small squares have a value of 3 units; the large squares, a value of 15 units. This grid is used for solving problems such as off-course correction, air plot, and radius of action, and for correcting reported wind (para 12-30).

b. *Correction Factors.* The F correction factors on the front side of the sliding grid are used for calculating TAS caused by compressibility of air at high airspeeds and altitudes. Army aircraft do not require the application of these correction factors to their TAS (fig 12-22).

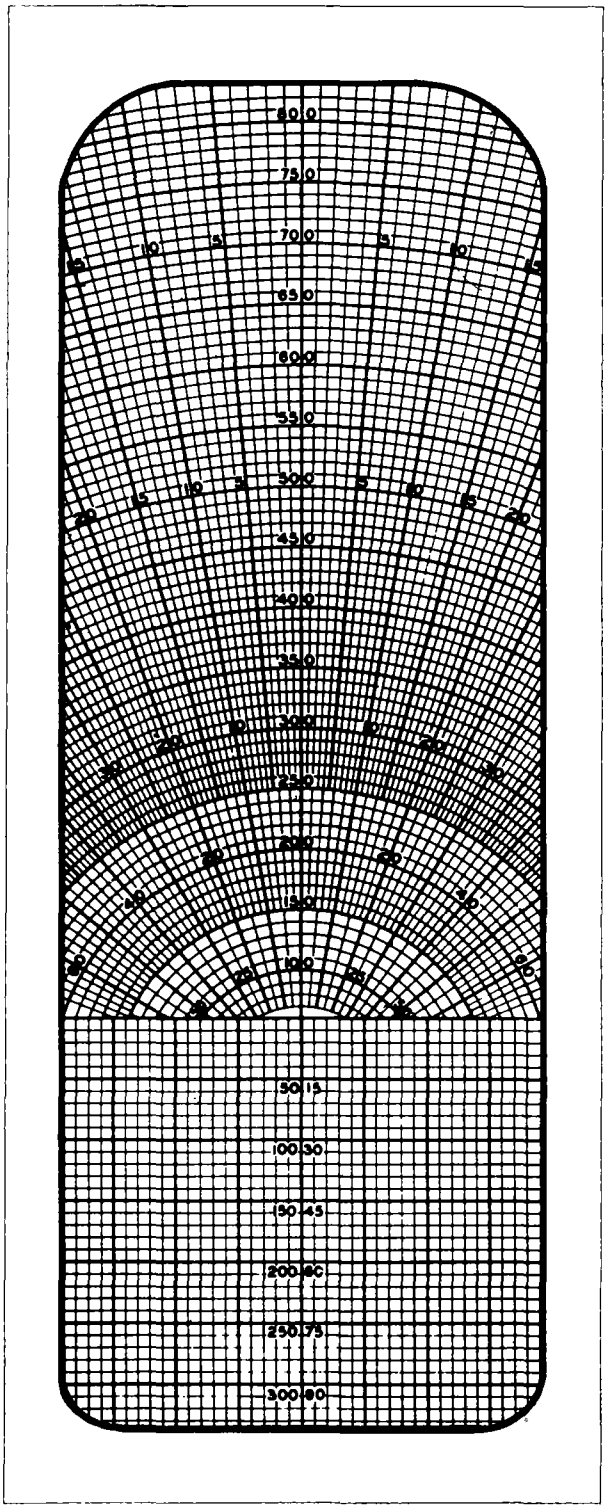


Figure 12-23. Reverse side of sliding grid.

Section IV. WIND TRIANGLES

12-23. WIND TRIANGLE SOLUTION

a. Problems involving wind can be solved by constructing a wind triangle. In its simple form, this triangle is made up of three vectors (six vector quantities) whose elements are always the same. The vectors (fig 12-24) are—

(1) A wind vector, consisting of the wind direction and speed.

(2) A ground vector, representing the movement of the aircraft with respect to the ground, and consisting of the course (or track) and the groundspeed.

(3) An air vector, representing the movement of the aircraft with respect to the airmass, and consisting of the heading and the true airspeed.

b. The direction of such vectors is shown by the bearing of a line with reference to north. The magnitude of the vector is shown by comparing the length of a line with an arbitrary scale. *For example,* if 1 inch represents 10 knots, then a velocity of 50 knots would be shown by a line 5 inches long (fig 12-24).

c. Necessary steps for drawing the wind triangle are—

(1) Draw a vertical reference line with an arrow at the top indicating north.

(2) Draw a very short line intercepting the reference line at a convenient point to indicate the point of origin in the diagram.

(3) Draw in the known vectors ("a" above).

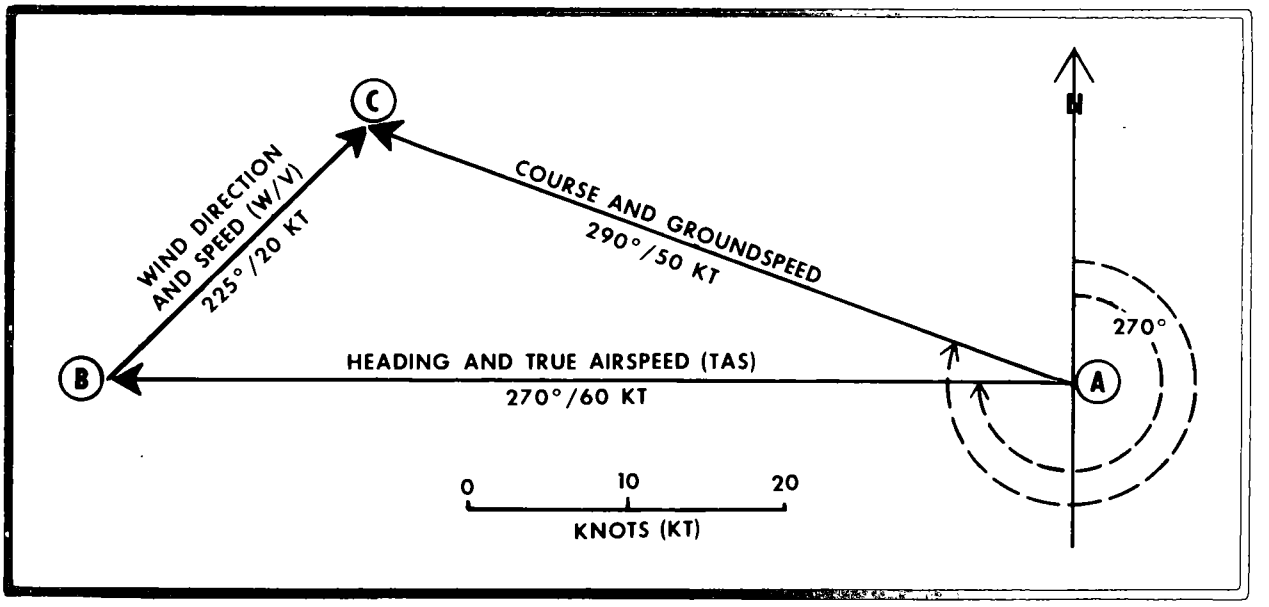


Figure 12-24. Representing the six vector quantities in a wind triangle.

(4) Close the triangle to determine two unknown factors. (Known and unknown factors will vary; but each factor can be determined, provided each vector includes its own factors, namely direction and length.)

[redacted] SOLUTION

Figure 12-25 illustrates the construction of a wind triangle to solve for heading and groundspeed when the course, wind velocity (W/V), and TAS are known. Similar triangles are used to solve for heading and TAS or for wind velocity.

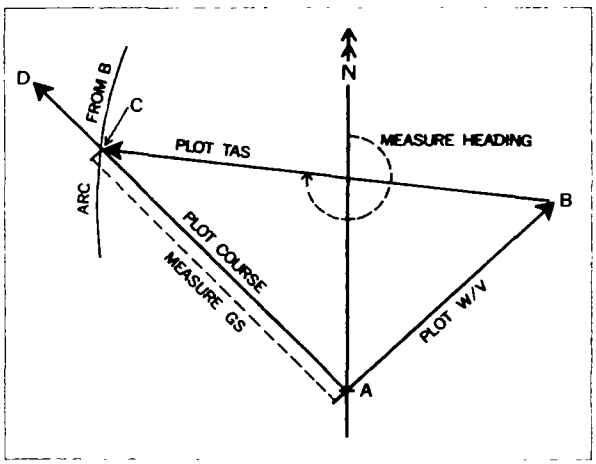


Figure 12-25. Solving for heading and groundspeed.

a. Plot the wind vector first (AB).

b. Plot the course for an indefinite distance from the point of origin (AD).

c. Swing an arc from the end of the wind vector (B) (using the TAS as the arc radius) to intersect the course line (C). Draw the air vector (BC).

d. Measure the heading by determining the angle formed between the vertical reference line and the air vector.

e. Measure groundspeed along the ground vector (AC).

Section V. WIND PROBLEMS

[redacted]

In solving wind problems on the computer, part of a triangle is plotted on the transparent surface of the circular disk. Lines printed on the slide are used for the other two sides of the triangle. The center of the concentric arcs (fig 12-26) is one vortex of the triangle. There are many methods applicable for computing any one problem, but the following method for each type of problem is standard for use by the Army aviator. This section includes problems where the *centerline* is used as ground vector and the *wind vector* is plotted *above* the grommet.

FM 1-5

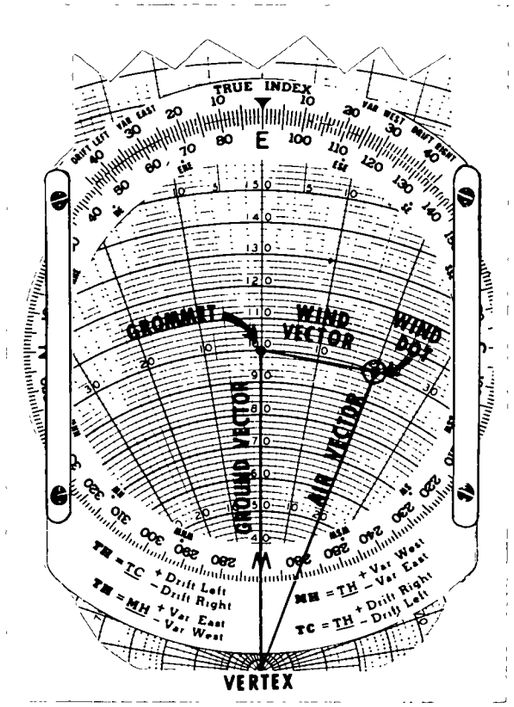


Figure 12-26. Wind triangle on DR computer.

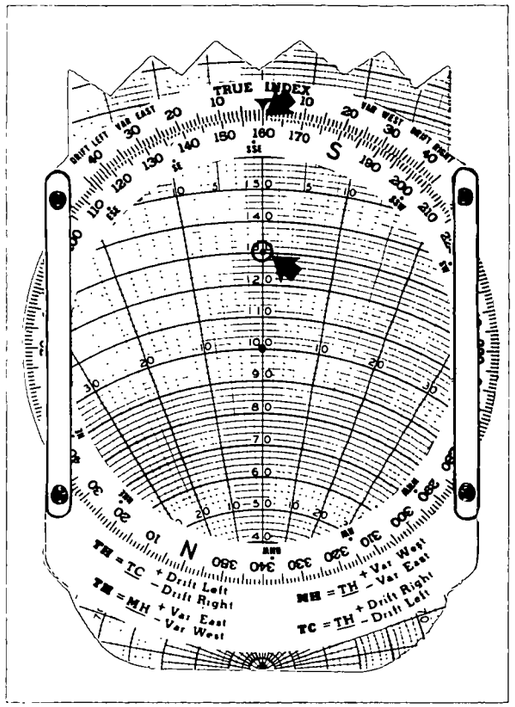
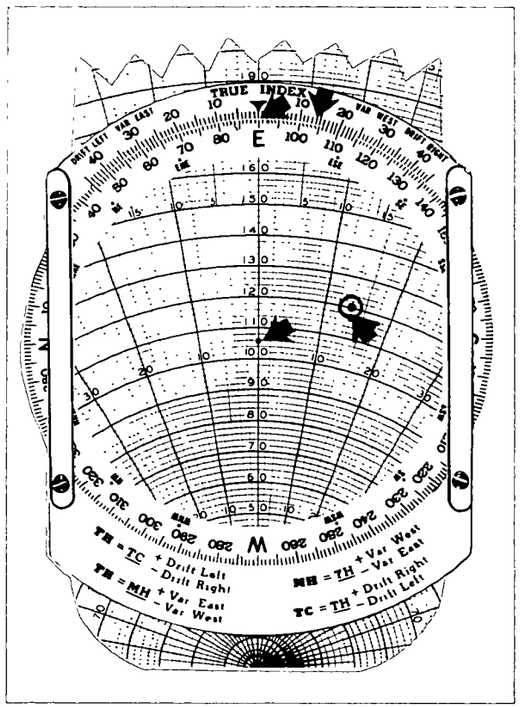


Figure 12-27. Plotting the wind vector to solve for heading and groundspeed.



Figures 12-28. Reading heading, wind correction, and groundspeed.

Note. **Directions used in solving wind problems *must* be compatible; i.e., all in reference to true north or all in reference to magnetic north.**

12-26. HEADING AND GROUNDSPEED COMPUTATION

a. *Problem.* The wind is from 160°/30 knots, the true airspeed 120 knots, course 090°. What is the heading and groundspeed?

b. *Solution.* Using the DR computer, refer to figures 12-27 and 12-28 and solve the problem as follows:

(1) Set 160° (direction *from* which the wind is blowing) to the TRUE INDEX (fig 12-27).

(2) Plot the wind vector *above* the grommet 30 units (windspeed) and place a wind dot within a circle at this point.

(3) Set 090° (course) at the TRUE INDEX (fig 12-28)

(4) Adjust sliding grid so that the true airspeed arc (120 kt) is at the wind dot.

(5) Note that the wind dot is at 14° converging line to the right of centerline.

(6) Under the 14° correction scale (labeled "DRIFT RIGHT") to the right of center at the top of the computer, read the heading (104°).

(7) Under the grommet, read the groundspeed (106 kt).

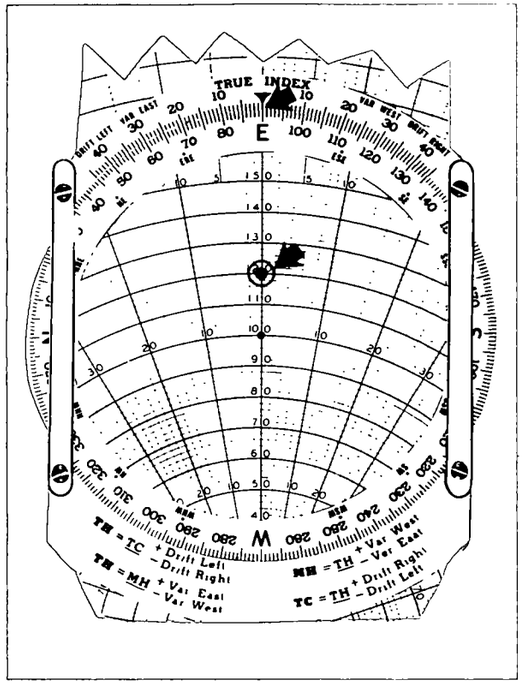


Figure 12-29. Plotting the wind vector to solve for heading and true airspeed.

[redacted]

a. *Problem.* The wind is from 090°/20 knots, course 120°, groundspeed 90 knots. What is the heading and true airspeed?

b. *Solution.* Using the DR computer, refer to figures 12-29 and 12-30 and solve as follows:

(1) Set 90 (090° wind direction) under the TRUE INDEX and plot wind vector 20 units above the grommet using dot within circle (fig 12-29).

(2) Set course (120°) to the TRUE INDEX (fig 12-30).

FM 1-5

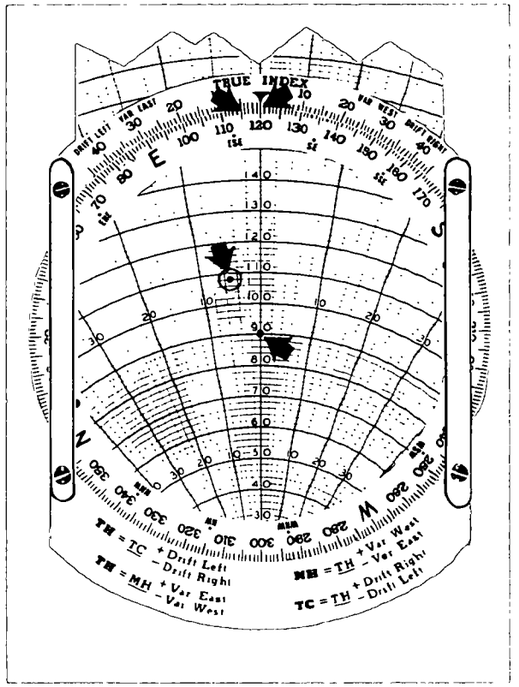


Figure 12-30. Reading heading, drift correction, and true airspeed.

(3) Move sliding grid so that groundspeed (90 kt) concentric circle is at the grommet.

(4) The wind dot is now on the converging line 5° to the left of centerline. Read the heading (115°) 5° left of TRUE INDEX on correction scale.

(5) Under the wind dot, read the true airspeed (180 kt).

[redacted]

a. *Problem.* Heading, 130°; true airspeed, 100 knots; track, 140°; groundspeed, 90 knots. What is the wind velocity?

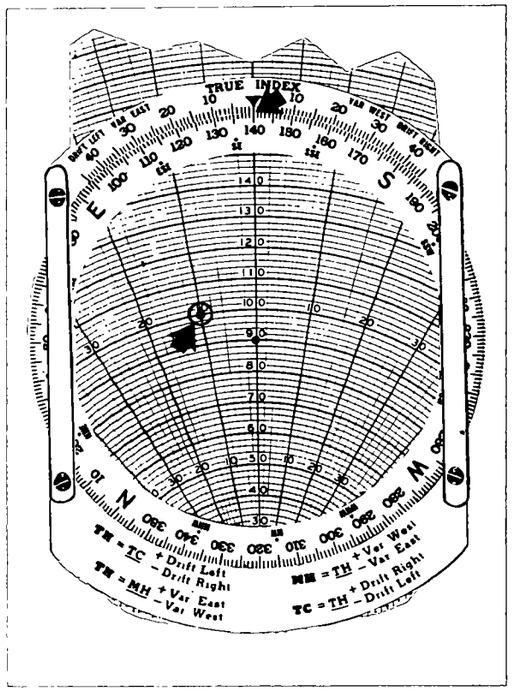


Figure 12-31. Solving for wind velocity.

b. *Solution.* Using the DR computer, refer to figures 12-31 and 12-32 and solve as follows:

(1) Set track (140°) at TRUE INDEX and grommet over the groundspeed (90 kt).

(2) Since the heading is 10° less than the track, find where the 10° converging line to the left of centerline crosses the 100-knot (true airspeed) line and place a dot within a circle at this point (fig 12-31).

(3) Turn circular grid until the dot is directly *above* the grommet (fig 12-32).

(4) Under the TRUE INDEX, read direction from which the wind is blowing

(075°). The distance in units between the dot and the grommet indicates the speed of the wind (20 kt).

12-23. CORRECTING THE REPORTED WIND

A pilotage fix, furnishing information on track and groundspeed, can be used for correcting the reported wind using the rectangular grid portion of the sliding grid.

a. *Problem.* After flying for 30 minutes, an aviator establishes a fix on a navigational chart and finds he is 6 miles north of his on-course dead reckoning position. The reported wind for the flight was 30 knots from 125°. What is the actual wind condition?

b. *Solution.* Place the rectangular grid of the slide under the transparent disk.

(1) Rotate the compass rose until the wind direction (125°) is under the TRUE INDEX (fig 12-33).

(2) Draw the wind vector down from the grommet (at 0) to the 30-knot point (A, fig 12-33).

(3) Reason the additional wind component; i.e., since the aircraft is 6 miles north of the desired position after 30 minutes flying time, the wind component is 12 knots (the aircraft would blow off course twice as far in 1 hour), and since the aircraft is drifting to the north, the wind is from the south.

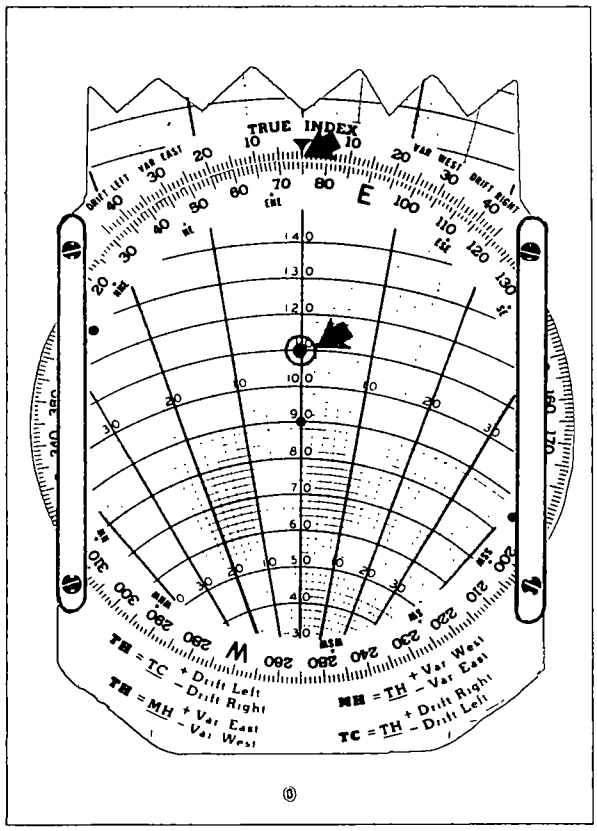


Figure 12-32. Reading wind velocity.

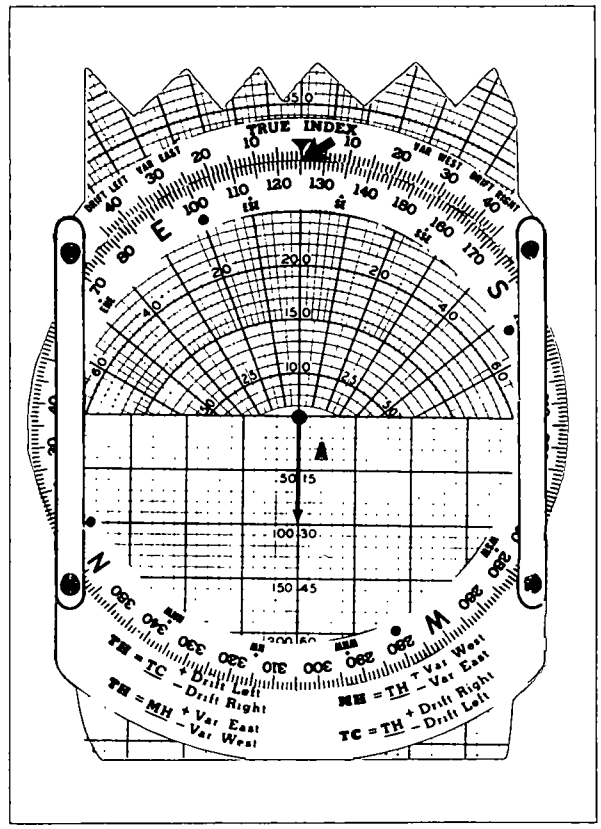


Figure 12-33. Plotting the reported wind.

(4) Rotate the compass rose until the letter "S" appears under the TRUE INDEX (fig 12-34).

(5) From the end of the first wind vector ((2) above), plot the additional wind component vertically downward 12 knots to scale (B, fig 12-34).

(6) Connect the end of this second wind vector with the point of origin of the first wind vector (the center of the disk) (C, fig 12-34).

(7) Rotate the compass rose until the corrected wind vector (C) lies along the centerline downward from the center of the disk (fig 12-35). Read the actual wind direction (140°) under the TRUE INDEX, and read the actual windspeed (38 kt) as the length of the vector (C) along the centerline.

12-30. WIND TRIANGLE VARIATIONS

a. Many other wind problems can be solved using the grid face of the CPU-26A/P computer, including track and groundspeed, wind and groundspeed from double or multiple drift, wind from groundspeed and drift, and correction for reported wind. Wind triangles may also be plotted on the computer, using the centerline as the air vector, by plotting the wind vector below the grommet.

b. Since the mastery of the wind triangle problems discussed in this section is adequate for flight planning with Army aircraft, a complete discussion of the variations mentioned in "a" above is not essential or within the scope of this manual.

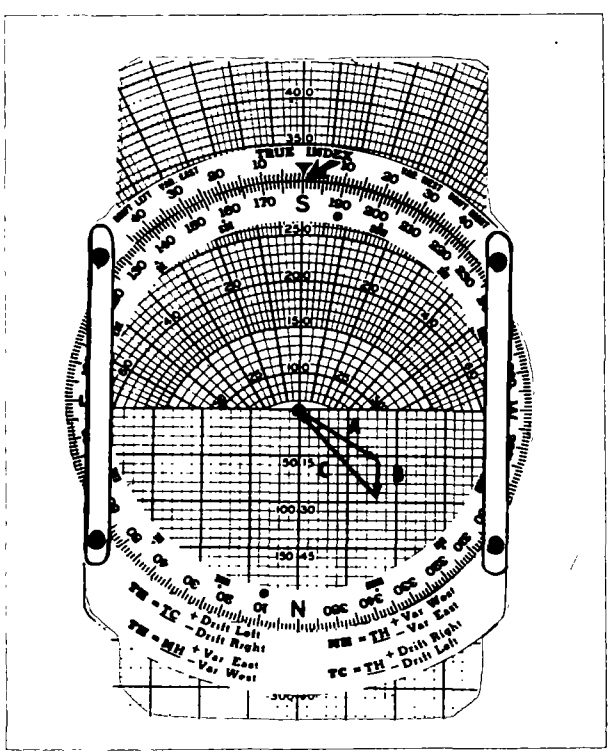


Figure 12-34. Plotting the assumed wind.

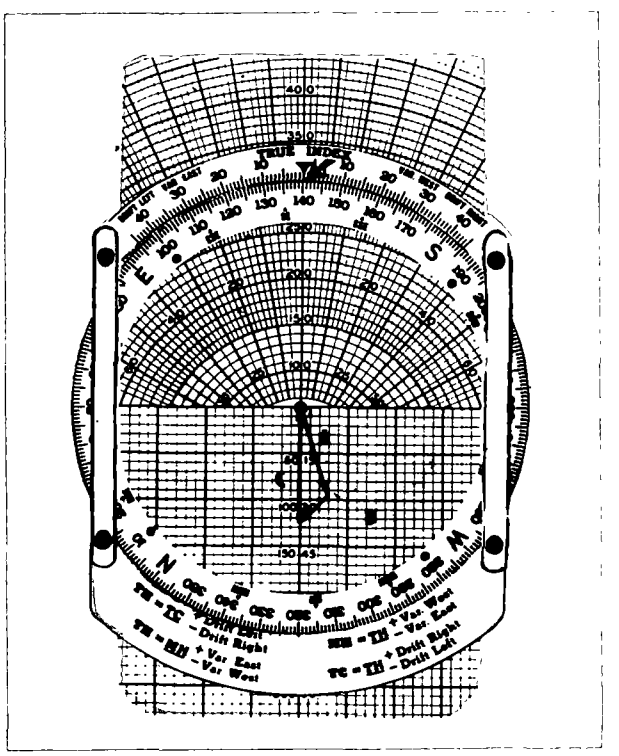
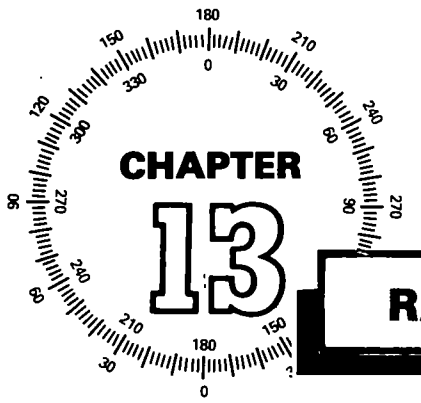


Figure 12-35. Plotting the actual wind.



CHAPTER 13

RADIO PRINCIPLES

13-1. GENERAL

Radio communication and radio navigation are necessary during instrument flight. The aviator should be familiar with radio principles and the capabilities and employment of Army aircraft radio equipment.

13-2. WAVE TRANSMISSION

According to the wave theory of radiation, sound, light, and electrical energy are transmitted by waves.

a. *Wave.* Energy transmitted through a substance or space by vibrations or impulse moves in waves. *For example,* when a stone is dropped into a pond, the energy of motion from the stone causes ripples on the water surface. The ripples (waves of energy) travel outward from the place where the stone struck the water, but the water itself does not move outward. The rise and fall above and below the normal undisturbed water level can be graphed as a curved line.

b. *Cycle.* A cycle is an *alteration* of a wave from a specific amplitude through a complete series of movements back to the same amplitude ("e" below); i.e., one complete wave vibration. A cycle (fig 13-1) is represented by the portion of the wave from A to E, from B to F, from C to G, or between any other two points encompassing exactly one complete amplitude variation. *For example,* a cork floating on calm water is subjected to cyclic wave movement when a stone is dropped into the water. One wave cycle occurs as the cork (1) rises from the calm water level (normal position) up to the wave crest, (2) drops back to normal, (3) falls into the wave trough, and (4) rises back to normal. A cycle is also completed when the cork moves from the crest of the wave down to the normal position, falls into the wave trough, rises back to normal, and continues rising to the top of the wave crest. Thus, a *cycle* is any complete sequence of amplitude variation in a repetitive series of wave movements.

c. *Frequency.* The frequency of a wave is measured by the number of cycles completed in 1 second. If two cycles are completed in 1 second, the wave frequency is two hertz (Hz). Since the number of hertz runs into high figures, radio frequencies are commonly expressed as kilohertz (kHz) (1,000 hertz) or megahertz (MHz) (1,000,000 hertz). Hertz is a unit of frequency equal to one cycle per second.

d. *Wavelength.* The linear distance of a cycle is known as the *wavelength.* In figure 13-1 the wavelength from A to E can be expressed in meters, feet, miles, or any other suitable linear measurement.

e. *Amplitude.* The *amplitude* of a wave is its magnitude measured from a specific reference level. In figure 13-1 the peak wave amplitude is represented by the lines BH, ID, or FJ; other amplitudes are shown as lines LM and NP. All representations were measured in linear distance above (+) or below (-) reference line AO.

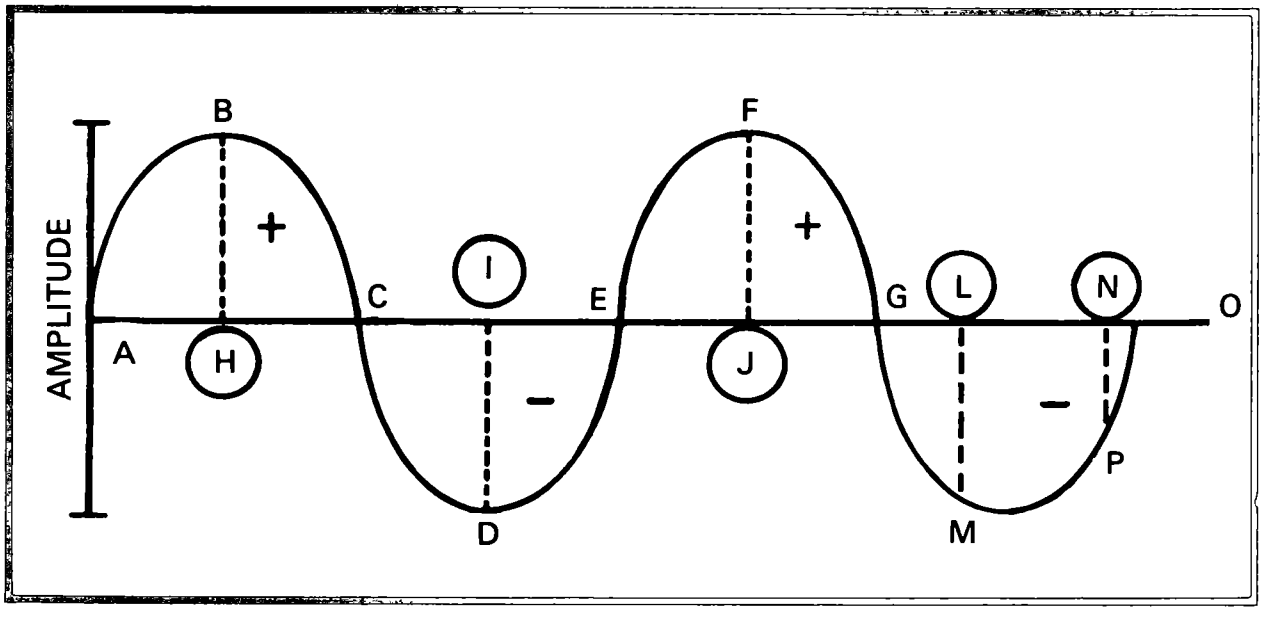


Figure 13-1. Wave representation (alternating current).

13-3. DIRECT CURRENT (DC) AND ALTERNATING CURRENT (AC)

An electrical current flows by the movement of electrons through a conductor. Direct current flows in only one direction. An alternating current flows in one direction for a time and then flows in the opposite direction for the same length of time, with a continuous movement. An alternating current (fig 13-1) can be represented as a continuous flow of electrons with half of each cycle being negative and the other half being positive.

13-4. RADIO WAVES

An electrical current builds up a magnetic field around the conductor through which it flows. When alternating current flows through a wire, the magnetic field around the wire alternately builds up and collapses. An alternating current of high frequency is used to generate radio waves which are emitted during the buildup and collapse of the magnetic field around a conductor (the antenna). Radio frequencies extend from 10 kilohertz to above 300,000 megahertz.

13-5. RADIO TRANSMITTER

a. *Generating and Transmitting a Radio Signal.* Fundamentally, a radio signal is transmitted by generating an alternating electric current of the desired frequency and connecting it to an antenna suitable for radiating that particular wavelength (fig 13-2). The current frequency is determined by the number of times per second that the alternating current changes direction of flow in the antenna.

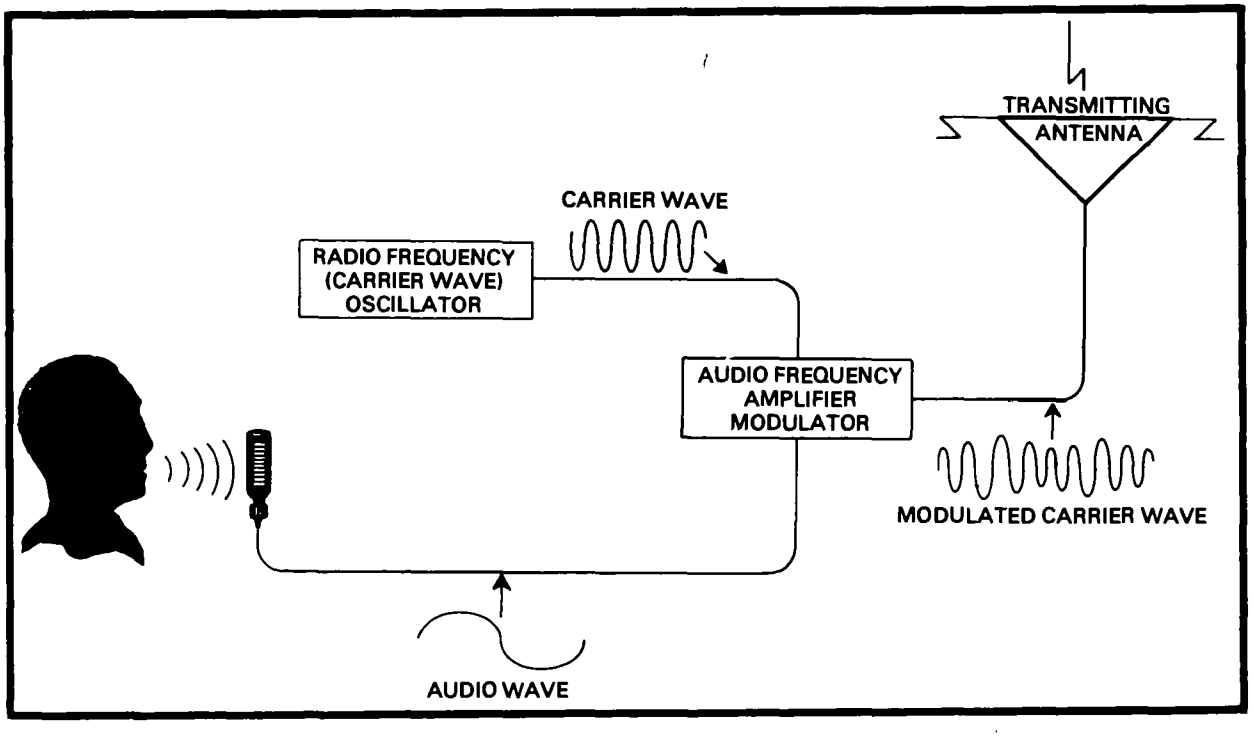
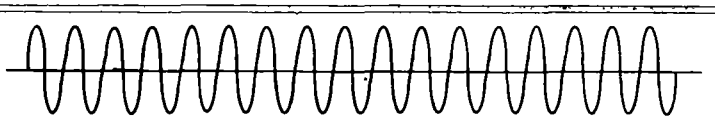
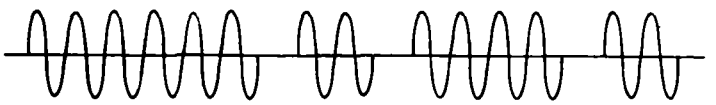


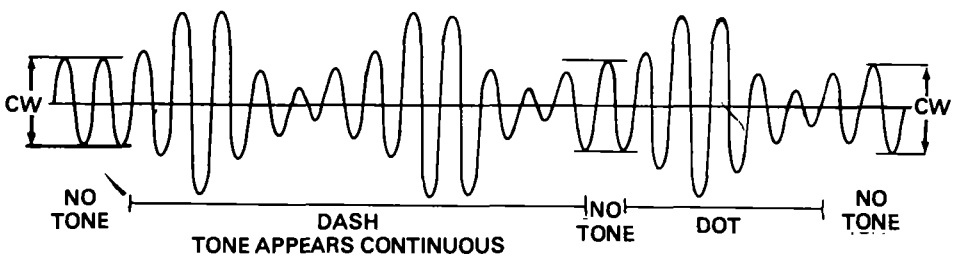
Figure 13-2. Radiotelephone transmitter schematic.



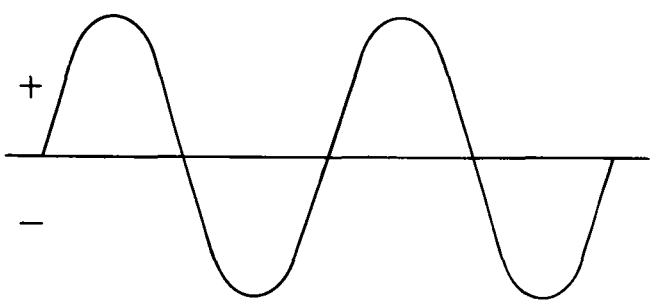
A. **CARRIER WAVE - continuous and unmodulated.**



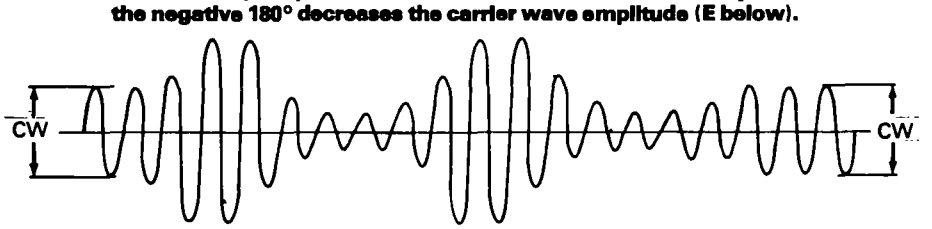
B. **INTERRUPTED CARRIER WAVE - for transmitting code.**



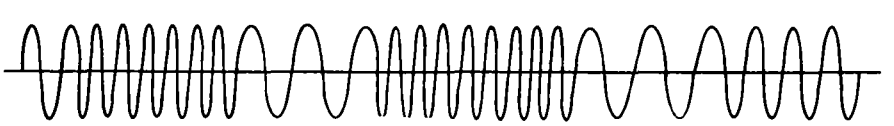
C. **CONTINUOUS WAVE MODULATED WITH TONE SIGNAL - modulation is interrupted to create code.**



D. **AUDIO WAVE - continuous audible tone signal. When superimposed on carrier wave, the positve 180° increases the carrier wave amplitude and the negative 180° decreases the carrier wave amplitude (E below).**



E. **CARRIER WAVE (A above) with audio wave (D above) superimposed by amplitude modulation (AM).**



F. **CARRIER WAVE (A above) with audio wave (D above) superimposed by frequency modulation (FM).**

Figure 13-3. Radio waves.

b. *Altering the Radiated Signal.* To transmit intelligible data, the radiated carrier wave (A, fig 13-3) is altered in some manner and these alterations are decoded at the receiver. Code is transmitted either by interrupting the carrier wave (B, fig 13-3) into a series of dots and dashes or by modulating the carrier wave with another steady tone (C, fig 13-3) which is interrupted to produce the desired code. Voice is transmitted by molding or modulating the carrier wave signal with audio wave transmissions (D, fig 13-3) generated through the radio microphone. The combined carrier wave and audio wave appear as in E, figure 13-3, if the audio wave is superimposed by amplitude modulation (AM) of the carrier wave. If the audio wave is superimposed by frequency modulation (FM), the combined wave will appear as shown in F of figure 13-3. Both AM and FM are used in transmitting voice to Army aircraft, but AM is the most common method. A modulated signal is commonly called *a modulated carrier wave* when either voice or tone signals are used in the modulation process. (C, E, and F of figure 13-3 represent modulated carrier waves.) Figure 13-2 illustrates voice modulation of a carrier wave.

13-6. PRINCIPLES OF THE RECEIVER (Fig 13-4)

a. *Tuning.* Radio waves induce minute electrical currents in receiving antennas. This process is the same as inducing an alternating current in one conductor by placing it near another conductor carrying alternating current. The method of selecting the desired signal from the many induced signals is called *tuning.* The tuning circuit in the receiver is adjusted to *resonance* with the frequency of the desired signal; other frequencies are rejected by the tuning circuit. The selected frequency is unintelligible at this receiving stage, since

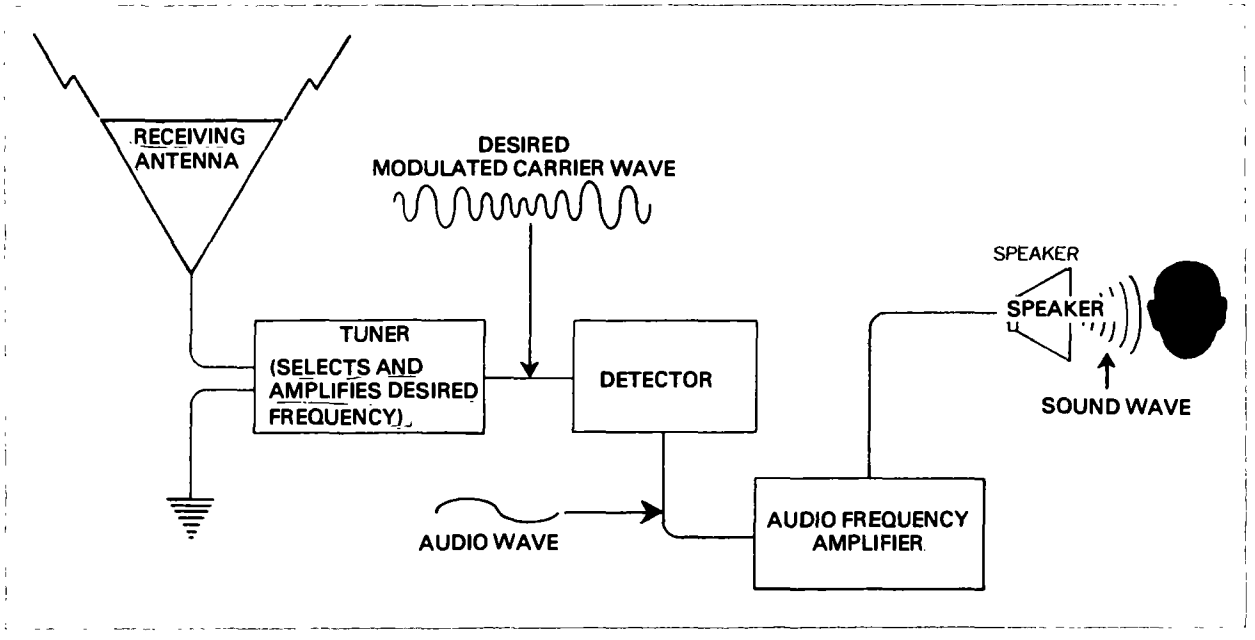


Figure 13-4. Radiotelephone receiver schematic.

it is still a combination of the radio wave (carrier wave) and the audio wave (voice).

b. *Demodulating.* Another stage of the receiver called a *demodulator* or *detector* is used to separate the audio wave from the carrier wave. The audio portion of the wave is amplified and used to vibrate the diaphragm of the headset or a speaker. This vibrating surface causes audible sound waves, reproducing those which entered the microphone at the transmitter (fig 13-4).

Note. **Since the frequency of a carrier wave is above the audible sound range, a beat frequency oscillator (BFO) (para 15-22b) is used to convert coded interrupted carrier wave signals into audible, intelligible sound.**

13-7. CLASSIFICATION OF FREQUENCIES

a. *Audio frequency (AF).* Twenty to 20,000 Hz.

b. *Radio frequency (RF).*

(1) Very low frequency (VLF), 10 to 30 kHz.

(2) Low frequency (LF), 30 to 300 kHz.

(3) Medium frequency (MF), 300 to 3,000 kHz.

(4) High frequency (HF), 3,000 to 30,000 kHz.

(5) Very high frequency (VHF), 30 to 300 MHz.

(6) Ultra high frequency (UHF), 300 to 3,000 MHz.

(7) Super high frequency (SHF), 3,000 to 30,000 MHz.

(8) Extremely high frequency (EHF), 30,000 to 300,000 MHz.

Note. **Although the Federal Communications Commission (FCC) designates 300 to 3,000 MHz as UHF, the UHF radio frequency band in aviation communication begins at 200 MHz.**

13-8. LOW FREQUENCY RADIO WAVE PROPAGATION (NONDIRECTIONAL)

A radio wave leaves the transmitting antenna in all directions. That portion of the radiated wave following the ground is called the *ground wave* (fig 13-5). The ground wave is conducted along the Earth until its energy is absorbed (depleted by the attenuation in process, para 13-10). The remainder of the radiated energy is called the *sky wave* (fig 13-5). The sky wave is radiated into space and would be lost were it not for the refracting layers in the atmosphere. These layers are in the region of the atmosphere called the *ionosphere* (region where air is ionized by radiation of the Sun). The refracting effect on the waves

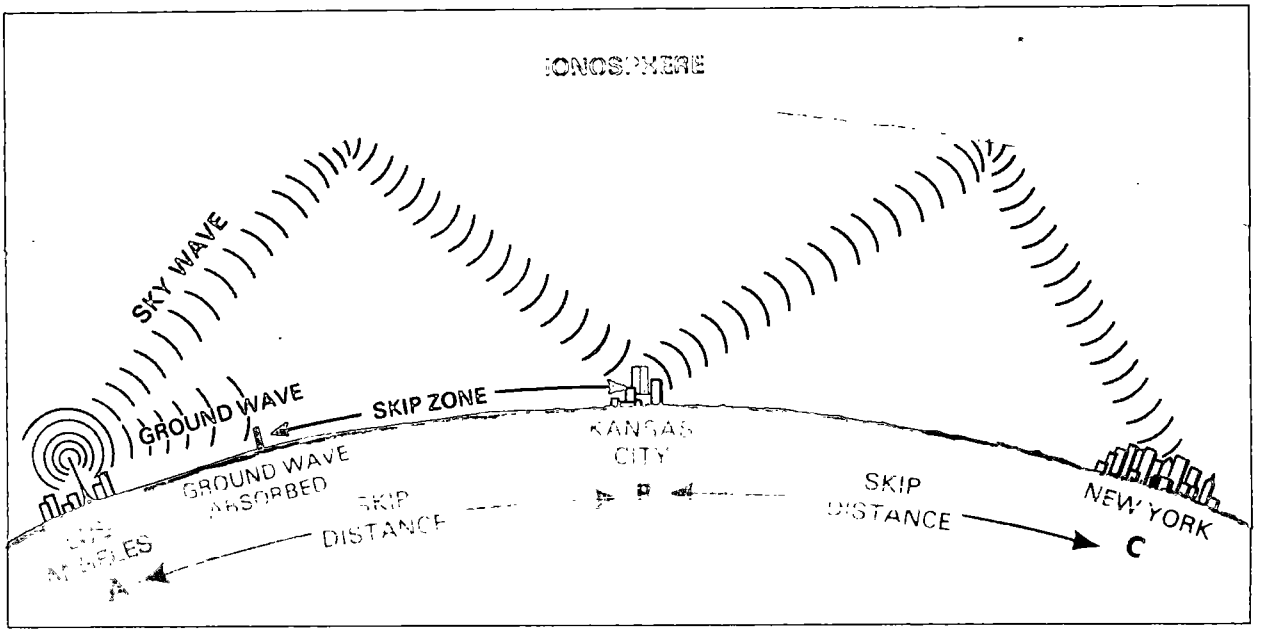


Figure 13-5. Radio wave transmission.

returns them to Earth and permits signals to be received at distant points. The effect on reception distance is determined by the height and density of the ionosphere and by the angle at which the radiated wave strikes the ionosphere. The ionosphere varies in height and density with the seasons, time of day, and latitude.

SKIP DISTANCE

The distance between the transmitting antenna and the point where the sky wave first returns to the ground is called the *skip distance* (AB, fig 13-5). By extension, this term also includes the distance between each surface reflection point in multihop transmission (BC, fig 13-5). The distance between the point where the ground wave can no longer be received and the point where the sky wave is returned is called the *skip zone*. Since solar radiation changes the position and density of the ionosphere, a great change in skip distance occurs at dawn and dusk, causing the fading of signals to be more prevalent than usual.

EFFECT OF ALL MATTER ON RADIATION

All matter within the universe has a varying degree of conductivity or resistance to radio waves. The Earth itself acts as the greatest resistor to radio waves. The part of the radiated energy that travels near the ground induces a voltage in the ground that subtracts energy from the wave. Therefore, the ground wave is attenuated (decreased in strength) as its distance from the antenna increases. The molecules of air, water, and dust in the atmosphere and matter at the Earth's

surface—such as trees, buildings and mineral deposits—also absorb radiation energy in varying amounts.

13-11. EFFECT OF STATIC UPON LOW AND MEDIUM FREQUENCY RECEPTION

Static disturbance is either manmade or natural interference. Manmade interference is caused, for example, by an ordinary electric razor. Each small spark, whether originating at a spark plug, contact point, or brushes of an electric motor, is a source of radiation. All frequencies from 0 to approximately 50 MHz are transmitted from each spark and, consequently, add their energy to any radio reception within this frequency range. Natural static may be divided into two types. Interference which originates from natural sources away from the aircraft is called *atmospheric static.* Interference caused by electrostatic discharges from the aircraft is called *precipitation* or *canopy static.*

13-12. GENERAL NATURE OF HF PROPAGATION (3,000 kHz to 30 MHz)

The attenuation of the ground wave at frequencies above approximately 3,000 kHz is so great as to render the ground wave of little use for communication except at very short distances. The sky wave must be used; and since it reflects back and forth from sky to ground, communication can be maintained over a long distance (12,000 statute miles, for example). Frequencies between LF and VHF produce the greatest radio transmission range between points on the Earth because they are refracted by layers of the ionosphere and follow the curvature of the Earth. The range of low frequencies is reduced by attenuation and atmospheric absorption, and VHF or higher frequencies penetrate the ionosphere and escape to outer space.

13-13. GENERAL NATURE OF VHF AND UHF PROPAGATION (30 to 3,000 MHz)

Practically no ground wave propagation occurs at frequencies above approximately 30 MHz. Ordinarily there is little refraction from the ionosphere, so that communication is possible only if the transmitting and receiving antennas are raised far enough above the Earth's surface to allow the use of a direct wave. This type of radiation is known as *line-of-sight* transmission. Thus, VHF/UHF communication is dependent upon the position of the receiver in relation to the transmitter. When using airborne VHF/UHF equipment, it is of utmost importance for the aviator to be aware of the factors limiting his communication range.

13-14. RANGE OF VHF AND UHF TRANSMISSION

The range of VHF and UHF transmission is limited primarily by the altitude of the aircraft and the power of the station. Both VHF and UHF are line-of-sight transmissions, and at 1,000 feet above level terrain are usable for approximately 39 nautical miles. At higher altitudes, VHF and UHF transmissions can be received at greater distances as indicated as follows:

1,000	39
3,000	69
5,000	87
10,000	122
15,000	152
20,000	174

CHAPTER 14

VHF OMNIDIRECTIONAL RANGE (VOR) SYSTEM

Section I. COMPONENTS AND OPERATION

[redacted]

The VHF omnidirectional range system is the primary navigational system used by Army aviators in the United States. The VOR is a VHF facility which minimizes atmospheric static problems and provides 360 usable courses to or from the station. The terms "omni" and "VOR" are often used interchangeably.

[redacted]

The transmitter emits two signals—the *variable signal* and the *reference signal.* The variable signal is transmitted in only one direction at any given time; however, the direction of its transmission varies so rapidly that the signal appears to be a continuous signal rotating clockwise around the station at approximately 1,800 rpm. Receivers which are correctly tuned to a station will receive both signals. The two signals are in phase *only* at magnetic north. At all other points around the station, there is a definite difference between the signals (fig 14-1). Receivers in the aircraft detect the phase difference and present the information to the aviator either by a centered indicator

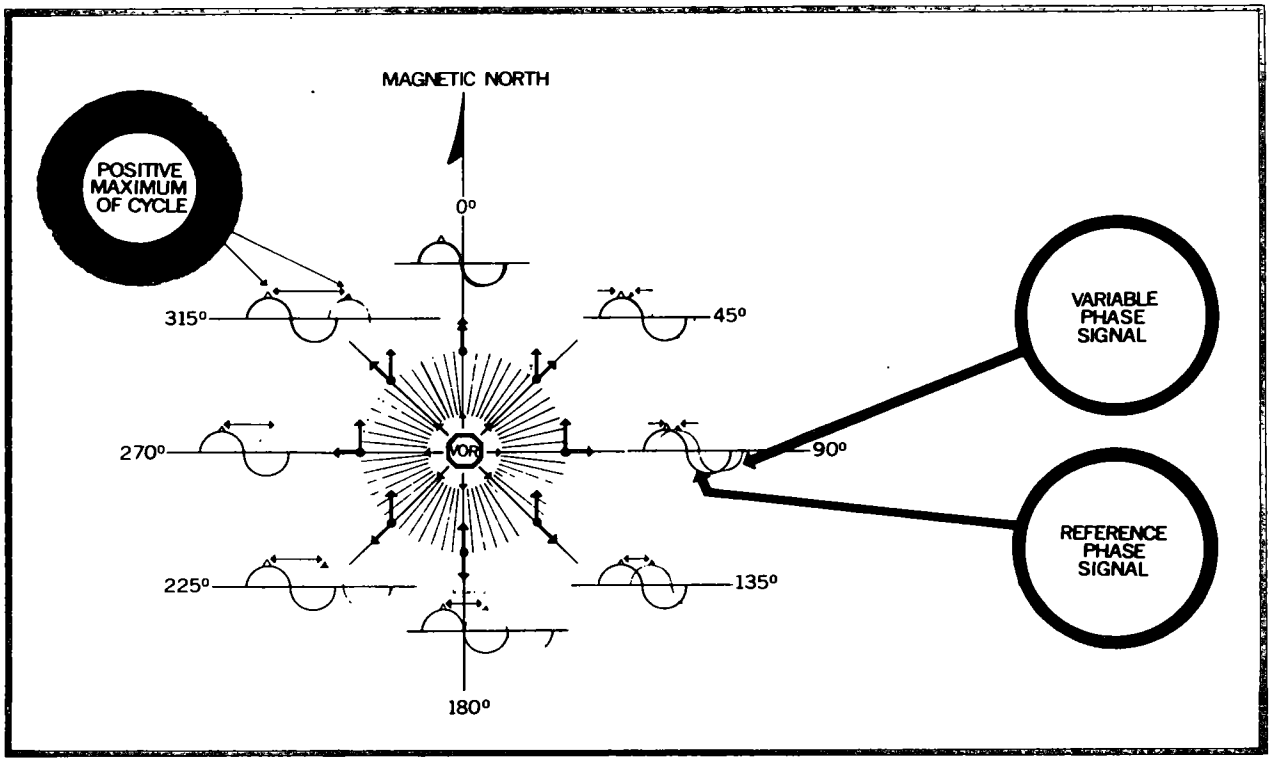


Figure 14-1. VOR signal phase differences.

needle representing an oncourse position or by a deflected needle to the right or left of center representing an off-course position. The signals may also be fed to a radio magnetic indicator (RMI) (fig 14-7) to show the magnetic direction to the transmitting station.

[redacted]

The Army uses several different VOR receivers in its aircraft. Detailed information concerning the set installed in each aircraft, including a description of the set, and the operating instructions are contained in the operator's manual.

[redacted]

The VOR navigation signal is displayed on an instrument called the *course indicator.* Several different types of course indicators are in use in Army aircraft. The most common are the ID-453 (fig 14-2), the ID-387 (fig 14-3), and the ID-1347 (fig 14-4). Detailed information concerning the course indicators installed in each aircraft is contained in the operator's manual.

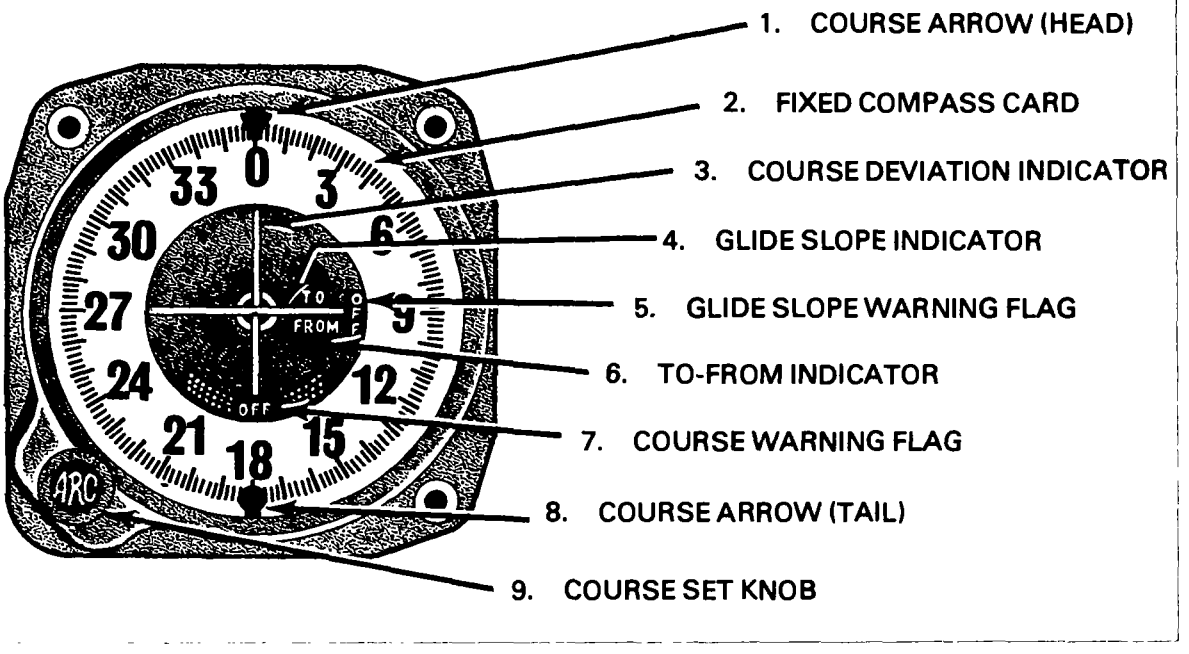


Figure 14-2. ID-453 course indicator.

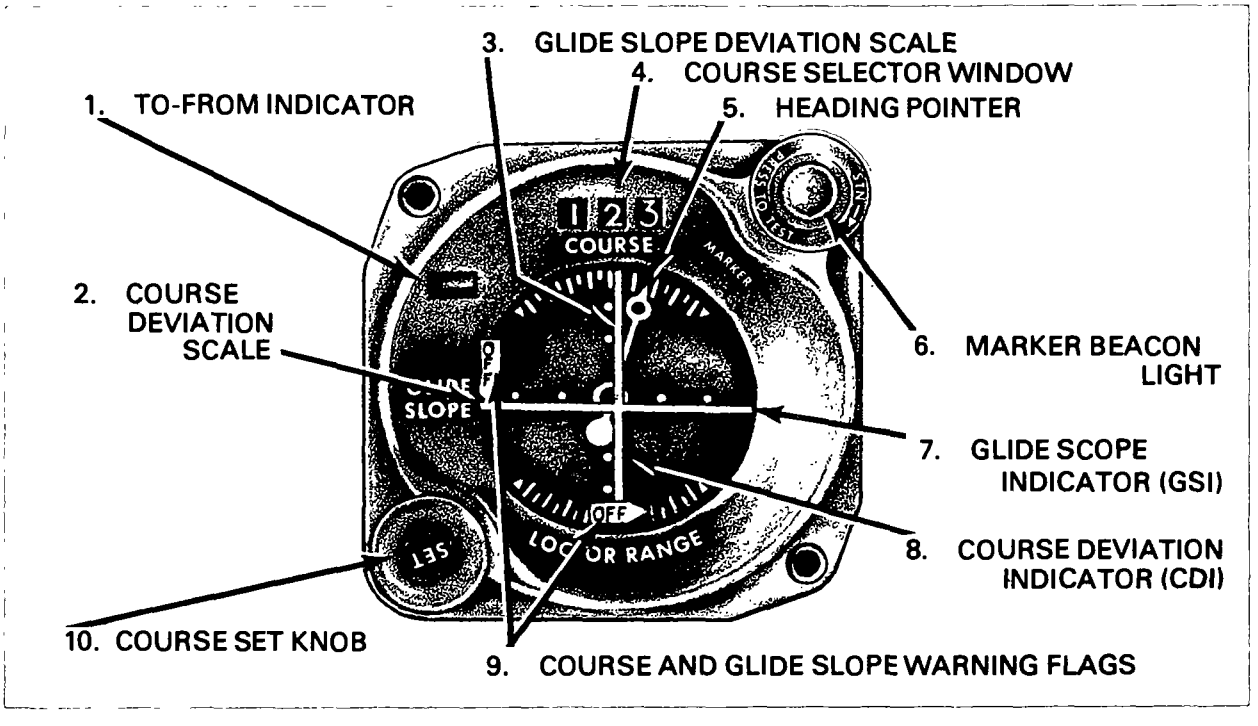


Figure 14-3. ID-387 course indicator.

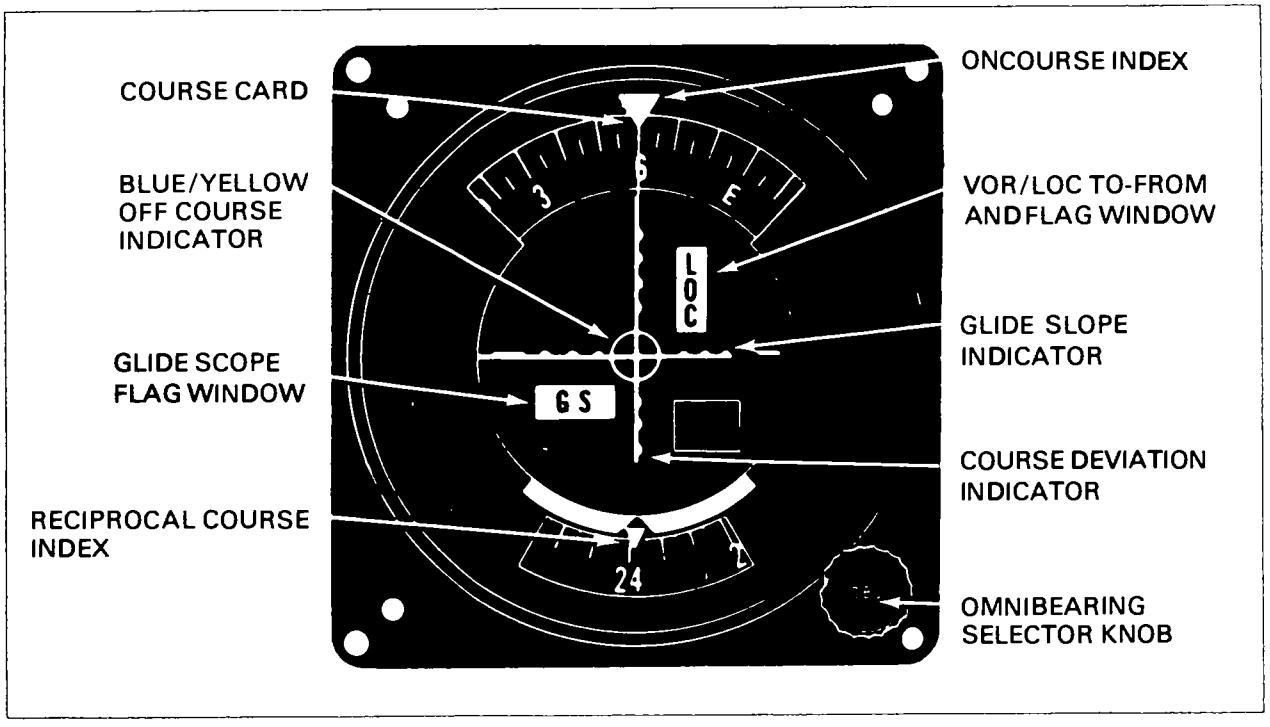


Figure 14-4. ID-1347 course indicator.

a. *Course Selector.* The course selector knob or omnibearing selector is manually operated to select the course that is desired for VOR navigation. The course selector places the course arrowhead (or pointer) or the course arrow tail (or ball) on the desired course (ID-453); or places the digits of the desired course in the course selector window (ID-387); or moves the course card to place the desired course number under the oncourse index or reciprocal course index (ID-1347) (fig 14-5).

b. *TO-FROM Indicator.* This indicator responds automatically to any course that is selected on the course indicator. It indicates whether the course selected, if flown, would take the aircraft to or away from the VOR station (fig 14-5). If the course selector is moved past a course which is 90° to the station, the TO-FROM

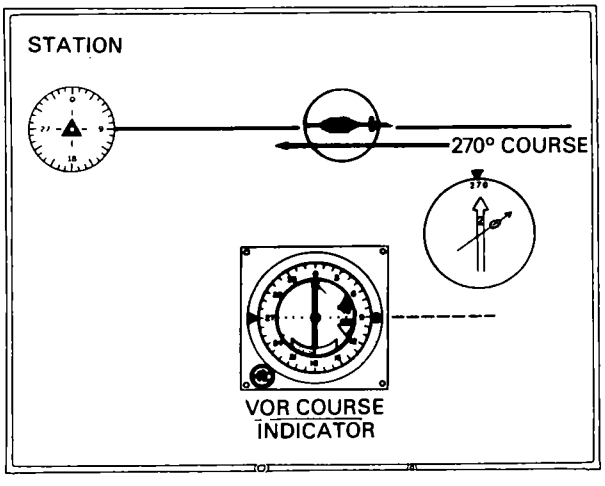


Figure 14-5. Course selector operation.

indication will change. When an aircraft flies across a radial which is 90° to the course selected, there may be a short period of time when the indicator display will be blank. Remember that the aircraft heading has no effect on the TO-FROM indicator.

c. *Course Deviation Indicator.* The course deviation indicator displays course deviation relative to the localizer course of the instrument landing system (ILS) or to a selected VOR course. Figure 14-6 shows the course indicator readings with respect to a selected course of 300° using the VOR.

Note. **The course deviation indicator is directional when the aircraft heading is within 90° of the course indicated by the course arrow.**

(1) *Needle centered.* When the aircraft is actually located on the selected course (aircraft A, B, and C, fig 14-6), the deviation needle is centered regardless of the aircraft heading.

(2) *Full-scale needle deflection.* If the aircraft is off the course by 10° or more

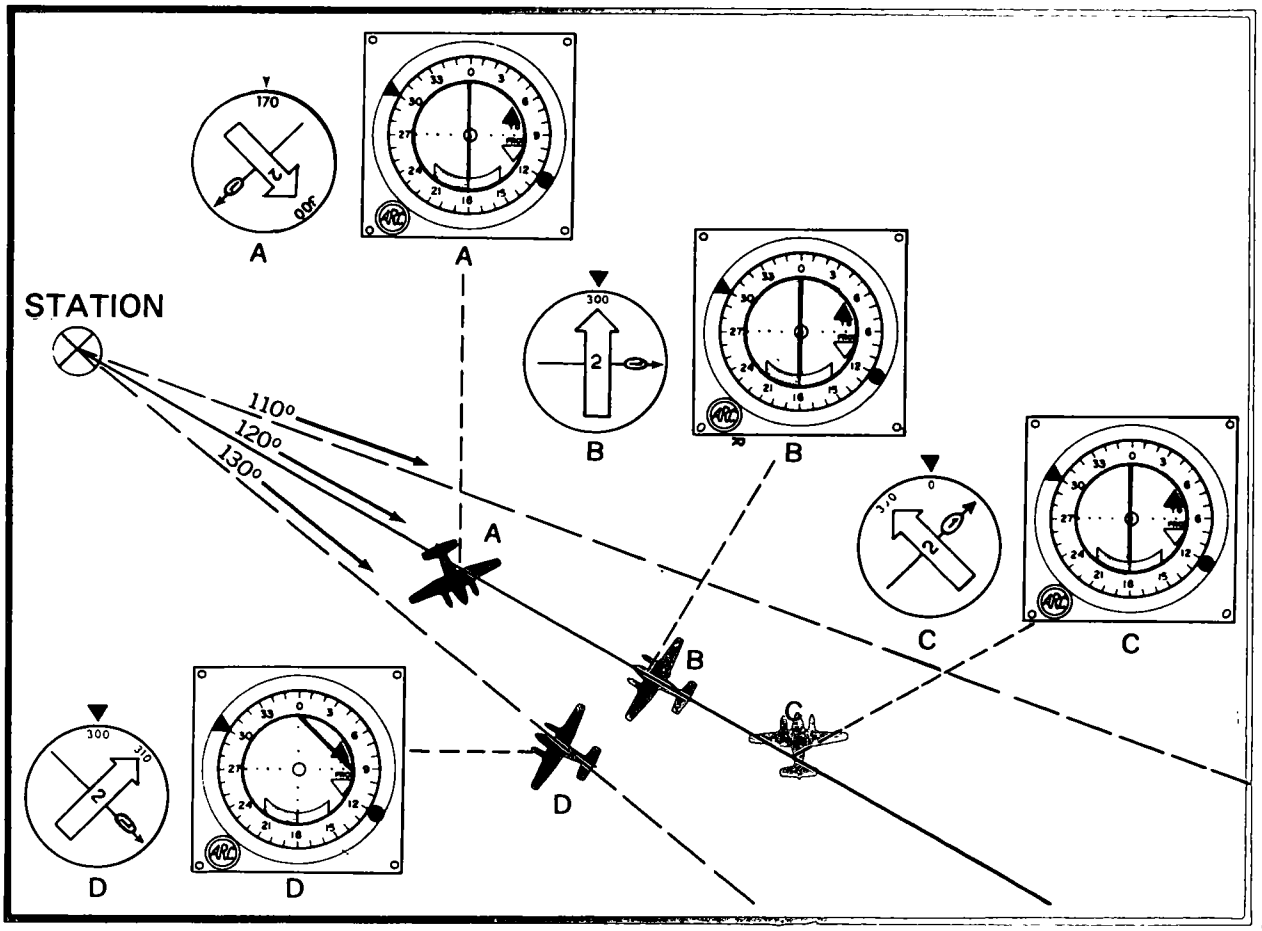


Figure 14-6. Deviation indicator operation.

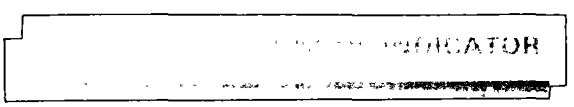
on VOR (dashed radials, fig 14-6), the needle deflects full scale to one side (aircraft D, fig 14-6). The course indicator face is graduated horizontally left and right from center with dots (course deviation scale) representing a deviation from course of 10° when using VOR and 2 1/2° when using the ILS localizer.

Note. Course deviation indicator displays, associated with [illegible] the ILS, will be [illegible] 21.

d. *Course and Glide Slope Warning Flags.* These warning flags are located in close proximity to the course deviation needle. There are two warning flags, one for the course deviation indicator (VOR or localizer) and the other for the glide slope. The flags are usually labeled "OFF"; however, on some course indicators the warning flags may not be located near the respective needle and will be labeled "LOC" for localizer and "GS" for glide slope. Appearance of the warning flag indicates that the respective indicator (course deviation indicator or glide slope) is not receiving a signal strong enough to provide reliable information.

e. *Glide Slope Indicator.* The glide slope indicator needle indicates whether the aircraft is on the glidepath or is deviating above or below the glidepath. The course indicator face is graduated vertically up and down from center with dots (glide slope deviation scale) representing a deviation from the glidepath up to 1/2°. The glidepath indicator is only activated when the receiver is tuned to an ILS frequency. Glide slope indicator displays will be illustrated in chapter 21.

f. *Heading Pointer.* The heading pointer (ID-387), connected to the course set knob and the compass system, displays aircraft heading relative to the selected course. When the aircraft heading is the same as the course selected, the heading pointer indicates 0° heading deviation at the top of the course indicator. The heading deviation scales at the top and bottom of the course indicator are scaled in 5° increments up to 45°.



The radio magnetic indicator (fig 14-7) consists of a compass card, a heading index, and two bearing pointers. It enables the aviator to determine simultaneously the present magnetic heading of the aircraft, the direction to and from the navigation facility to which the No. 1 bearing pointer is coupled,and the direction to and from the navigation facility to which the No. 2 bearing pointer is coupled.

a. *Compass Card.* The compass card is actuated by the aircraft's slaved gyro compass system (chap 2). When working properly, the card shows the magnetic heading under the heading index.

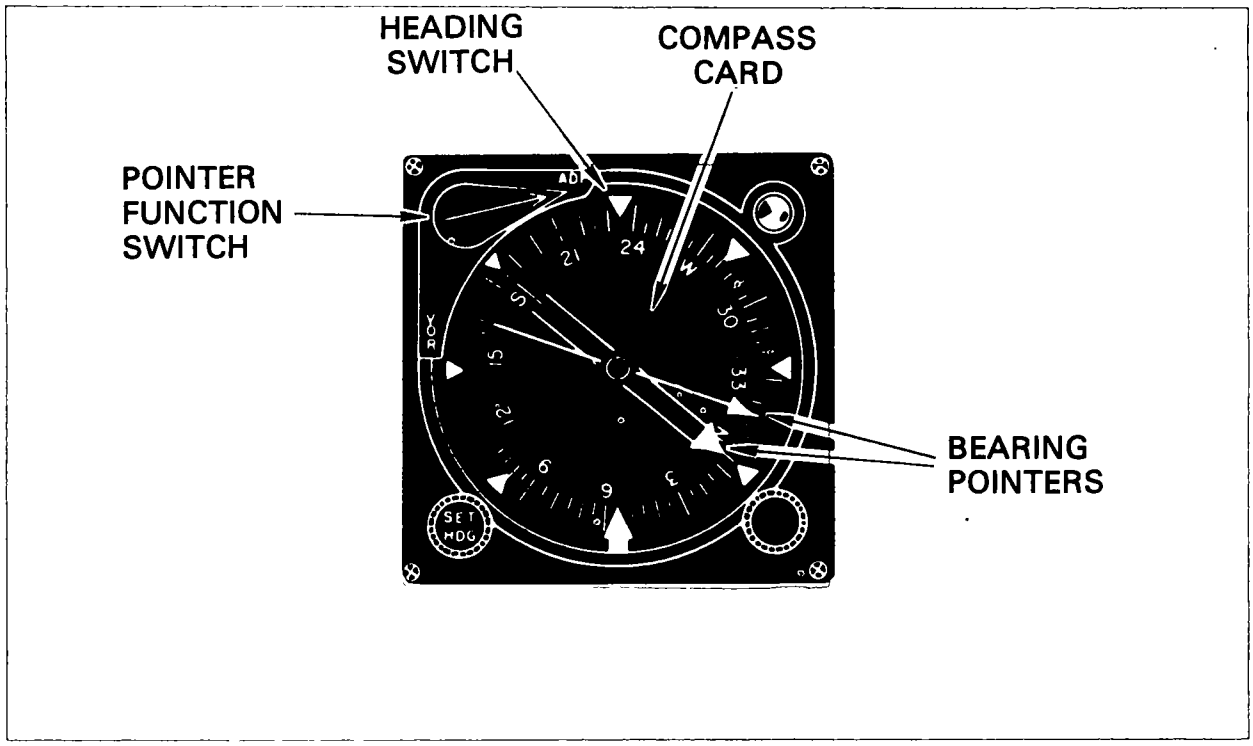


Figure 14-7. Radio magnetic indicator (RMI).

> *Note.* **A preflight cross-check of the compass card with a known heading (magnetic compass) should always be made.**

b. *No. 1 and 2 Bearing Pointers.* These two bearing pointers are actuated by either the VOR, tactical air navigation (TACAN), or automatic direction finder (ADF) radio receivers.

Caution: Bearing pointers will not function in relation to the instrument landing system.

Each bearing pointer, when coupled to a navigation receiver, will indicate the direction to the navigation facility being received. Based on the number and type of receivers installed, there are several coupling arrangements possible. Normally the No. 1 bearing pointer will be connected to the ADF receiver and the No. 2 to the VOR receiver. Information or coupling arrangements for specific aircraft types and models can be found in each aircraft operator's manual. A bearing pointer that can be coupled to either a VOR receiver or an ADF receiver will have this coupling accomplished by the position of the pointer function switch.

Section II. FLIGHT PROCEDURES USING THE VOR

[redacted]

VOR flight procedures using the course indicator and the radio magnetic indicator will be discussed. When the aviator has both of these navigation instruments in operation, he may use the indications of either or both of these instruments to accomplish VOR flight procedures. Where the RMI is included in an illustration, the No. 2 bearing pointer will be coupled to the VOR receiver and will indicate the magnetic bearing to the VOR which is tuned in the receiver. The opposite end or tail of the needle will indicate the radial from the VOR station on which the aircraft is located. The No. 1 bearing pointer displayed in the figures of this chapter is nonfunctional.

[redacted]

The set will be turned on and placed in operation in accordance with the instructions in the operator's manual for the aircraft. Place the desired VOR station frequency on the frequency selector dial. Positively identify the station by its repeated three-letter Morse Code group, or a three-letter Morse Code group alternating with a recorded voice identifier. If required, move the pointer function switch to the VOR position.

14-8. TUNING

a. *Courses and Radials.* The desired course is selected with the course selector (para 14-4a). The term "radial" refers to a course emanating from a VOR station. On navigation charts, courses are published as directions outbound from the VOR stations (radials). It is frequently convenient to refer to the position of an aircraft in terms of the radial on which it is located; *for example,* figure 14-8 shows three aircraft on the 090° radial. Aircraft A is on the 090° radial following a 270° course inbound to the station. Aircraft B is on the 090° radial following a 090° course outbound from the station. Aircraft C is crossing the 090° radial flying a heading of 320°. In each position the No. 2 bearing pointer indicates the course to the VOR station and the opposite end of the needle indicates the radial.

b. *Orientation Procedure.* Without moving the course selector (unless TO or FROM is not indicated) visualize a line (red line, fig 14-9) drawn between the pointer and ball (ID-453) or visualize a compass rose on the face of the ID-387 and the ID-1347 with a line drawn from the course selected to its reciprocal. Then visualize a line drawn 90° through this course line (blue line, fig 14-9). Note

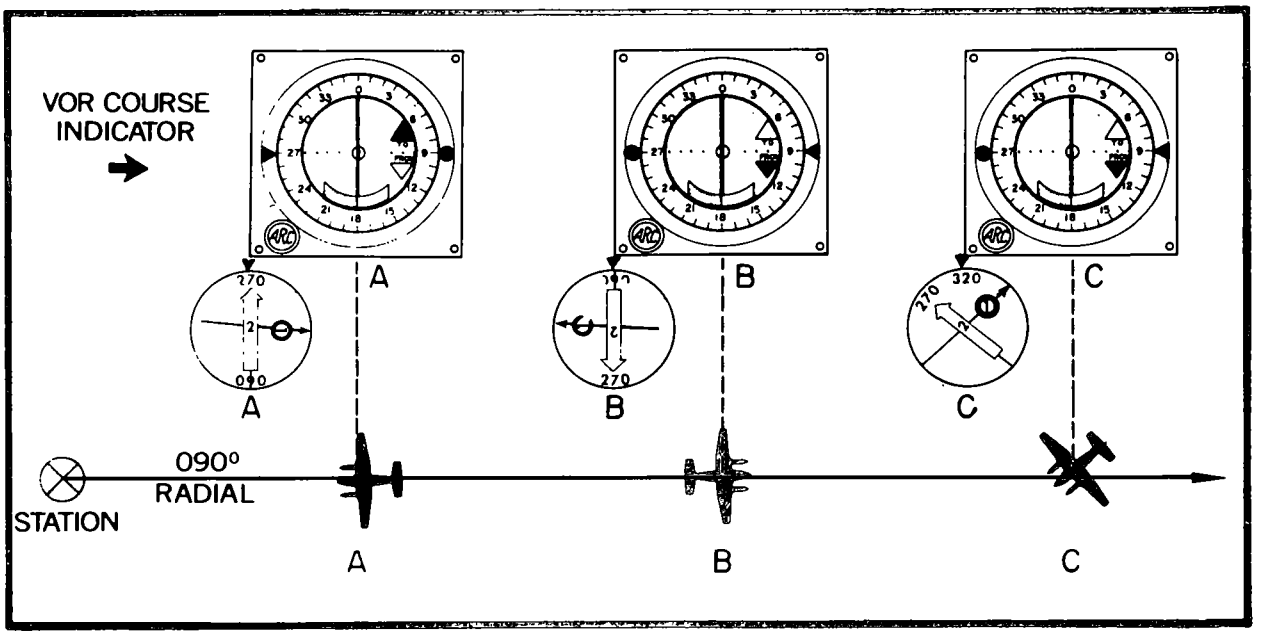


Figure 14-8. Relationship of aircraft positions as described by radial, course, or heading.

position of the TO-FROM indicator. In figure 14-9, there is a "TO" indication. This indicates that the aircraft is in the sector north of the blue line. Next, note the position of the course deviation needle. It is deflected to the right, indicating that the aircraft is east of the red line. Therefore, the aircraft is located in the quadrant between the 345° radial and the 075° radial. Now move the ball to the right within this quadrant until the course deviation needle centers. The position of the ball will indicate the radial that the aircraft is on. Another orientation method is as follows: Rotate the course selector until the TO-FROM needle reads "TO" and the course deviation needle is centered. Now the course to the station is known. The reciprocal of this course is the radial upon which the aircraft is located. An alternate procedure is to center the course

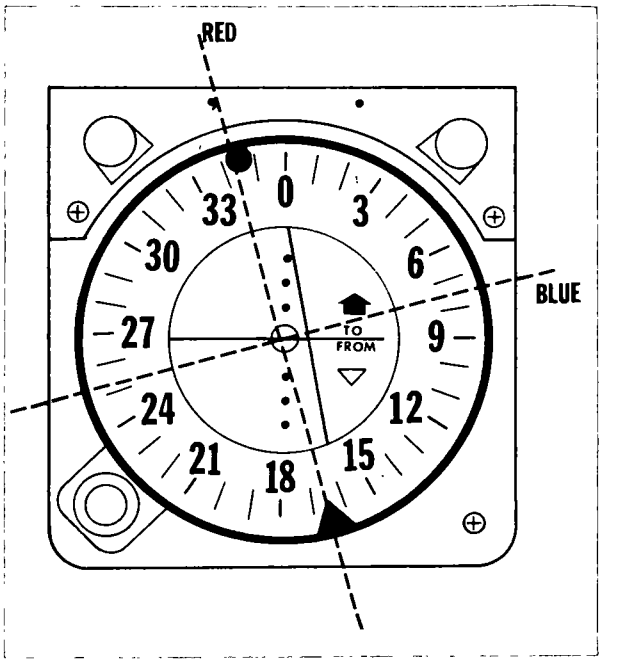


Figure 14-9. Use of course deviation indicator in orientation.

deviation needle with a "FROM" indication. Now the course away from the station is known. This course is also the radial upon which the aircraft is located. When an RMI is used with the VOR receiver, the above orientation procedures are not required. When the receiver is tuned to a VOR, the bearing pointer of the RMI will indicate the magnetic heading to the station and the opposite end of the needle indicates the radial upon which the aircraft is located. The aviator is now oriented in relation to the VOR station.

The procedures for maintaining a course to a station are illustrated in figure 14-10. The aircraft is maintaining a 360-degree course to the VOR station.

a. *Position A.* In position A, the aircraft is on course; the course deviation indicator needle is centered, the TO-FROM indicator indicates "TO" and the bearing pointer indicates "360°."

b. *Position B.* In position B, the aircraft has been blown off course approximately 5°. The crosswind is from the left and the course deviation indicator is deflected to the left. The bearing pointer indicates "335°." To return to the course, the heading must be corrected to the left. The standard correction under normal wind conditions is 20° for aircraft with airspeed at or above 90 knots (kt) and 30° for aircraft operating below 90 knots.

c. *Position C.* In position C, a heading change of 20° is applied. The aircraft heading is now 340°.

d. *Position D.* In position D, the aircraft has returned to the course—the course deviation indicator needle has recentered. The bearing pointer again indicates "360°." If the present heading of 340° is maintained, the aircraft will fly through the course. If the aircraft is returned to the original heading of 360°, the aircraft will be blown off course again.

e. *Trial Drift Correction.* To avoid both situations, the heading is changed by turning toward the course by half the amount of the initial correction; i.e., turning toward the course 10° (15° if flying below 90 kt). The aircraft heading is now 350°. This results in the first trial drift correction for the crosswind. This drift correction may later prove to be either correct, too small, or too large.

(1) *Correction too small.* If the first trial drift correction (10°) is too small (wind is stronger than anticipated), the aircraft will again be blown off course from point E to point F (fig 14-11). The heading must again be changed to 340° (G, fig 14-11) in order to intercept the course. The aircraft reintercepts the course at point H. A heading correction (I, fig 14-11) is made by turning toward the course 5° to a heading of 345°. (The aircraft is now using a total drift correction of 15°.) This bracketing procedure will be repeated as necessary until a heading is selected that maintains the aircraft on course.

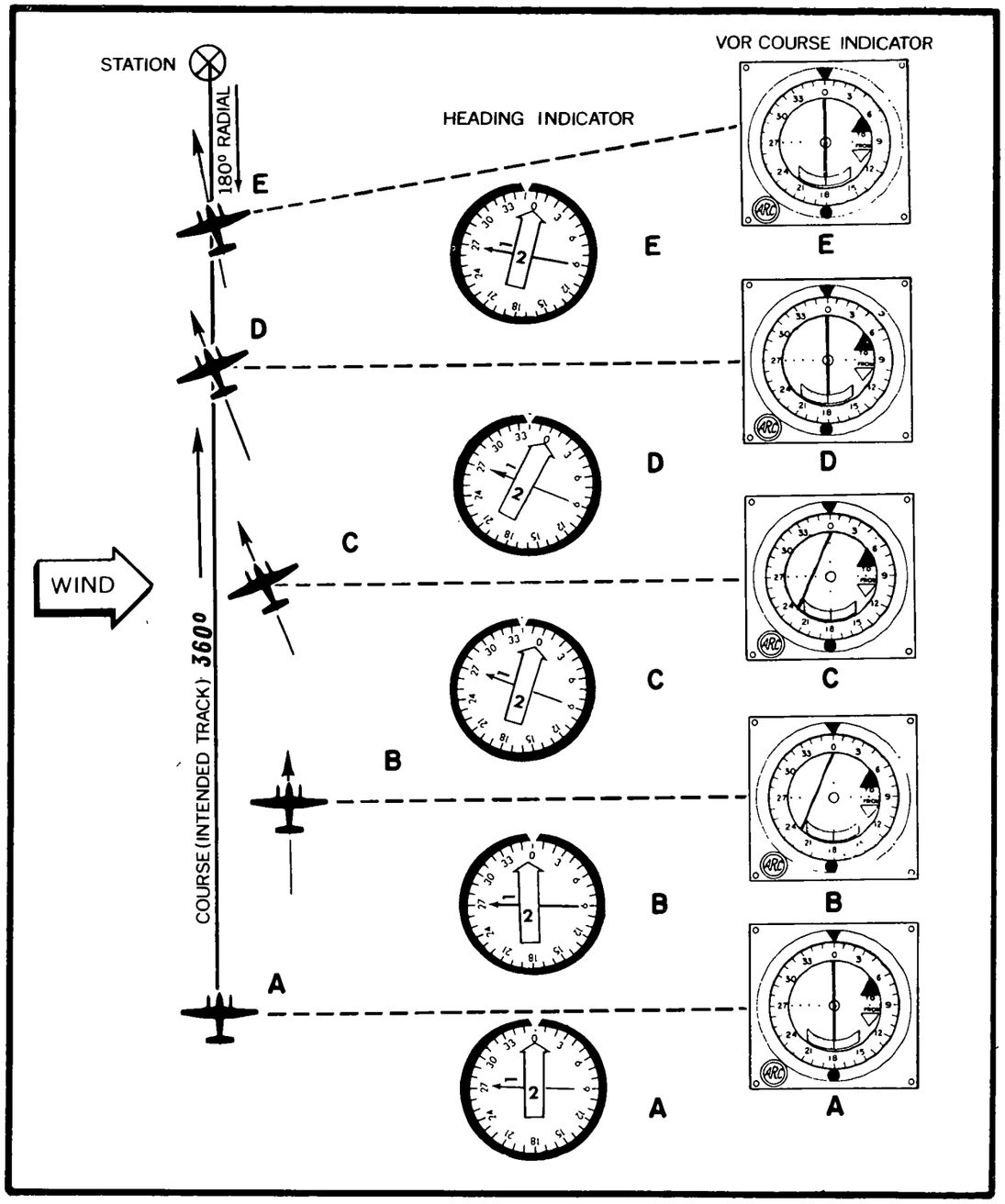


Figure 14-10. Maintaining a course to a station (VOR).

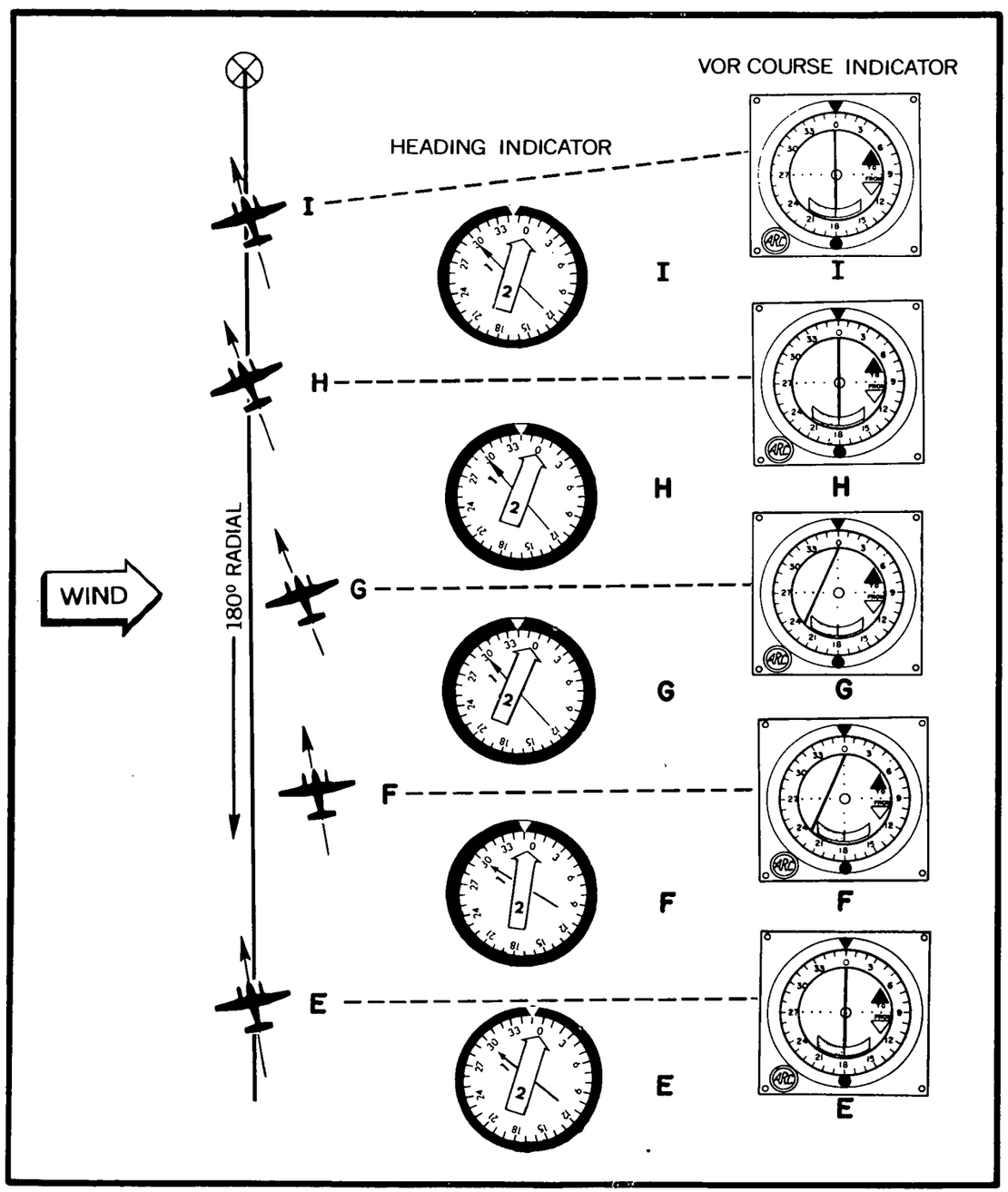


Figure 14-11. Trial drift correction too small (VOR).

(2) *Correction too large.* If the first trial drift correction (10°) is too large (wind not quite as strong as expected), the aircraft will fly off course upwind. In figure 14-12, the aircraft is overcorrecting at point U and flies off course into the wind at point V. The aircraft is returned to the course by returning to a heading of 360° (point W) and allowing the wind to blow the aircraft back on course at point X. When back on course, a 5-degree drift correction (not as large as the initial correction) is applied into the wind (a 10-degree drift correction is applied for flying below 90 kt). The heading of the aircraft is now 335°. If this heading maintains the course, no further heading change is required.

(3) *Correction for unusually strong wind.* On some occasions, unusually strong winds will prevent the aircraft from returning to the course even when a 20-degree or 30-degree correction is used. If, after applying a 20-degree or 30-degree correction, the course is not reintercepted in a reasonable period of time, a correction of 40° or more may be required in order to return to the course. It must be assumed that if 40° is required to return to the course, approximately half of the correction (in this example 20°) may be required to stay on course.

OPEN FOR FOLDOUT

Note. Course maintenance procedures discussed here are for guidance only; in flight, these procedures are refined to suit specific flight conditions.

FM 1-5

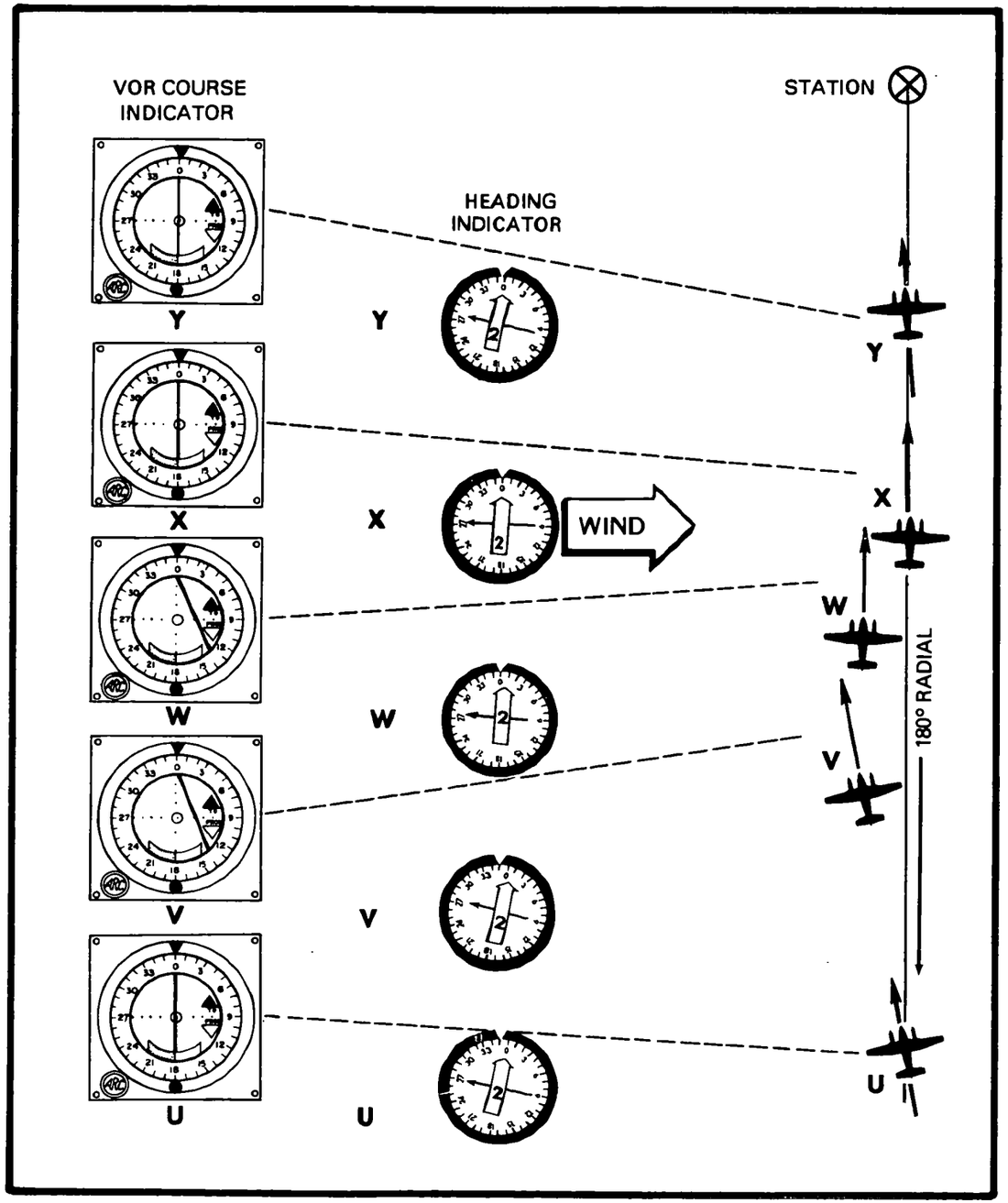


Figure 14-12. Trial drift correction too large (VOR).

[redacted]

Recognition of station passage is very important because VOR stations are used to fix an exact position. These stations are also used as holding points for air traffic control (ATC) and are often the destination point of an instrument flight rules (IFR) flight to be used during the instrument approach to the airfield. Station passage is determined as follows:

a. Since the approximate arrival time over a station is known, the aviator watches the clock and, as this time approaches, observes the reaction of the TO-FROM indicator.

(1) While inbound to the station, the indicator will read "TO."

(2) As the aircraft passes over the station, the TO-FROM indicator will fluctuate momentarily, then indicate "FROM." The time that this occurs is station passage time. Also, when flying over the station, fluctuations of the deviation needle and the momentary appearance of the warning flag will occur. At this time, station passage will also be indicated by the RMI bearing pointer moving to the reciprocal of the course.

b. If the flight is to be continued on the same course, the procedures for maintaining a course (para 14-9) should be followed. The only indicator change is the reversal of the TO-FROM indicator and the reversal of the RMI bearing pointer. If there is a course change (fig 14-13), the course selector is set to the new course and the aircraft turned to a heading that will place it on the new course.

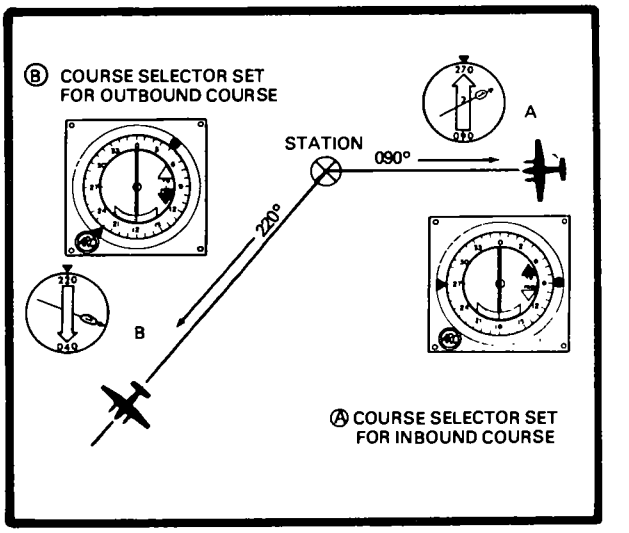


Figure 14-13. Course selector reset to fly outbound on a different course.

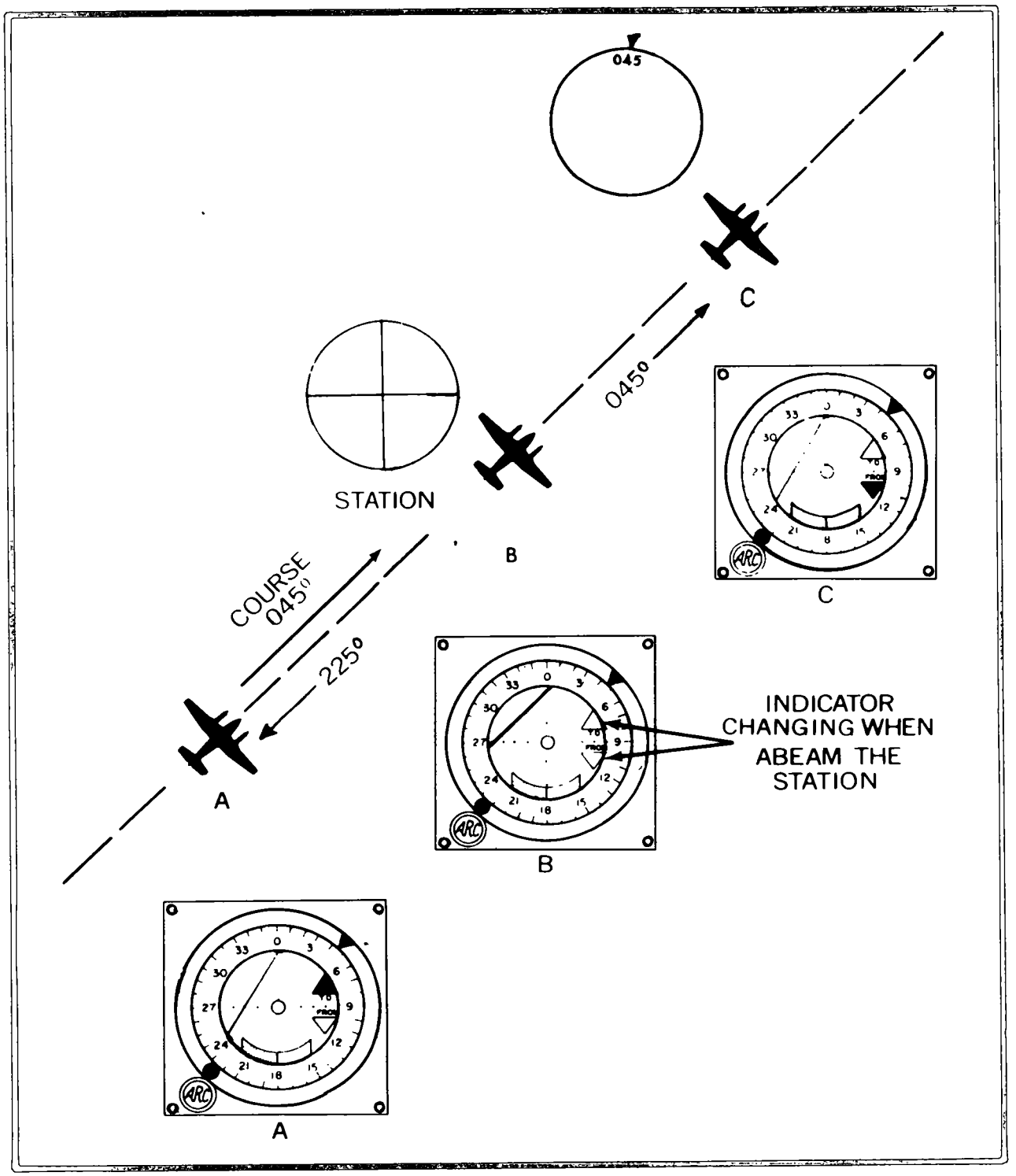


Figure 14-14. TO-FROM indicator changes abeam the station.

c. Figure 14-14 illustrates another important consideration when the TO-FROM indicator reading changes. The aircraft is flying a heading of 045° (point A), but is *not* inbound on the selected course to the station of 045°. The aircraft continues on the same heading and flies past the station (point B). At the time the aircraft is abeam the station, the TO-FROM indicator will momentarily have no indication, then will change to read "FROM." This "FROM" reading will remain in the indicator as the aircraft flies away from the station (point C).

14-13. POSITION FIXING

a. The Victor (V) airways system (see note below) is based upon the operation of several hundred VOR stations and has, in addition to the stations themselves, numerous other flight checkpoints (intersections). An *intersection* is a point where two or more radials from different VOR stations intersect. Checkpoints can be established at these intersections for position fixing. The procedure for fixing position over intersections by using one VOR receiver (course selector reading "FROM") is illustrated in figure 14-15.

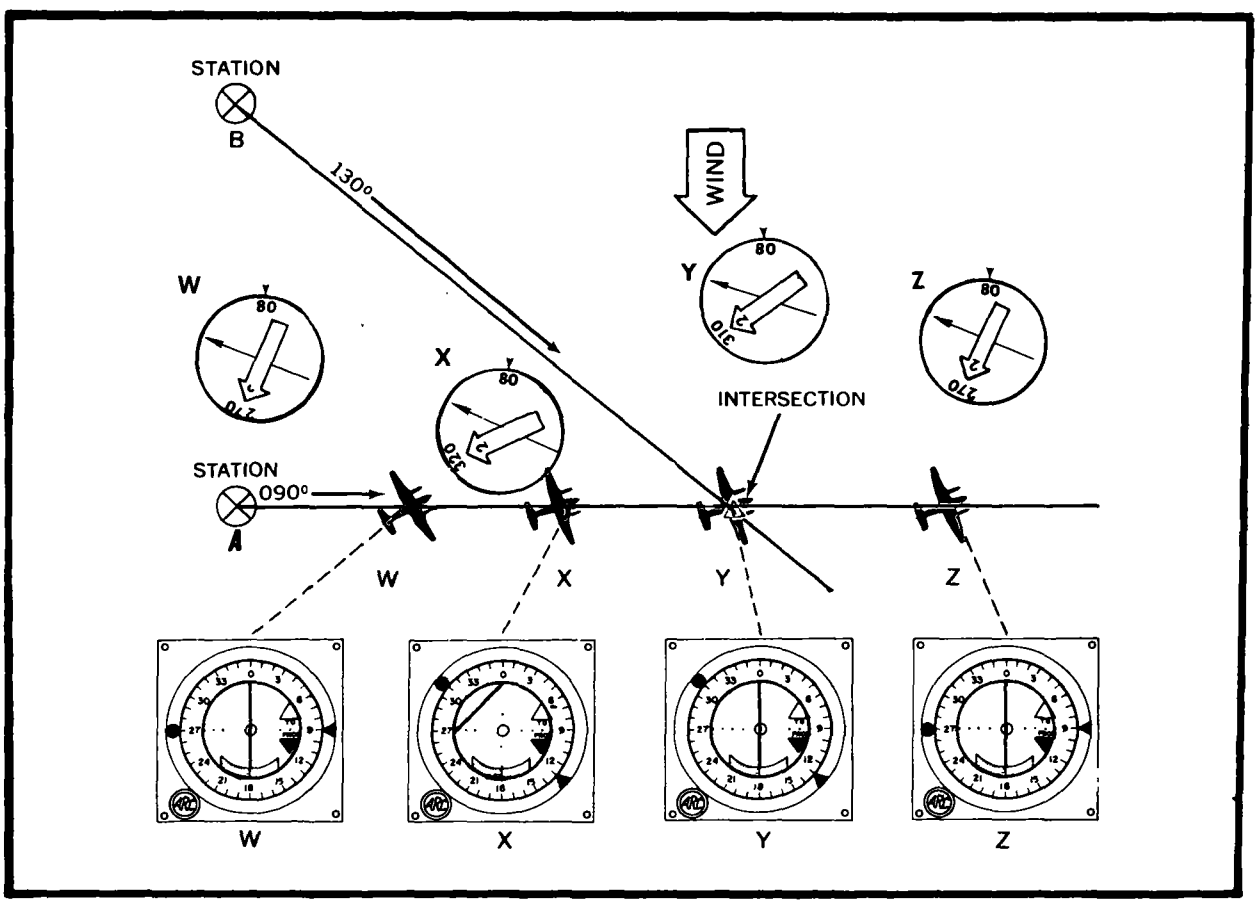


Figure 14-15. Position fixing at an intersection, course selector reading, "FROM."

Note. **Established routes for the purpose of air route traffic control (ARTC) of enroute IFR traffic have been designated and charted. These routes are called airways in the low altitude route structure (below 18,000 feet mean sea level (MSL)) and jet routes in the high altitude route structure. Victor airways use VOR facilities and are labeled with a "V" and a number; i.e., "V-241." The north-south airways have odd numbers and the east-west airways have even numbers. Jet routes are similar to airways except that they are labeled with a "J" and a number; i.e., "J-80."**

(1) The aircraft proceeds outbound (W, fig 14-15) from station A with the receiver tuned to station A. During this outbound flight, the correct heading for remaining on the course (090°) is determined by the procedures outlined in paragraph 14-9.

(2) After establishing the desired heading to remain on a 090° course, station B is tuned and identified.

(3) The 130° radial from station B crosses the 090° radial from station A to establish the intersection (open triangle symbol). The course selector is set on 130°, and since this is the radial from the station, the TO-FROM indicator will read "FROM" (X, fig 14-15).

(4) At the time the aircraft is exactly over the intersection (Y, fig 14-15), the deviation indicator will center since the aircraft will then be on the 130° radial from station B. Also, the No. 2 bearing pointer will indicate 310° at the intersection. After the intersection is determined, the course selector is reset to 090°, station A is tuned and identified, and course maintenance procedures resumed.

b. In performing the procedure discussed in "a" above, it is important to be able to interpret the direction of needle deflection. In the situation depicted in figure 14-15, the needle is deflected to the left while the aircraft is at point X. Prior to arrival at the intersection, the deviation indicator will be deflected to the same side on which the station is located if the course selector has been set on the published *radial* which causes the TO-FROM indicator to read "FROM."

c. It may be convenient or necessary to fix an intersection by setting the course selector for a "TO" reading, as illustrated in figure 14-16. In flying from station A to station B, the aircraft is to be turned inbound to station B when it arrives over the Gamma intersection.

(1) The aircraft departs station A outbound, with the course selector set on 010°, the deviation indicator centered (on course), and the TO-FROM indicator reading "FROM" (W, fig 14-16).

(2) Prior to reaching the Gamma intersection, station B is tuned and

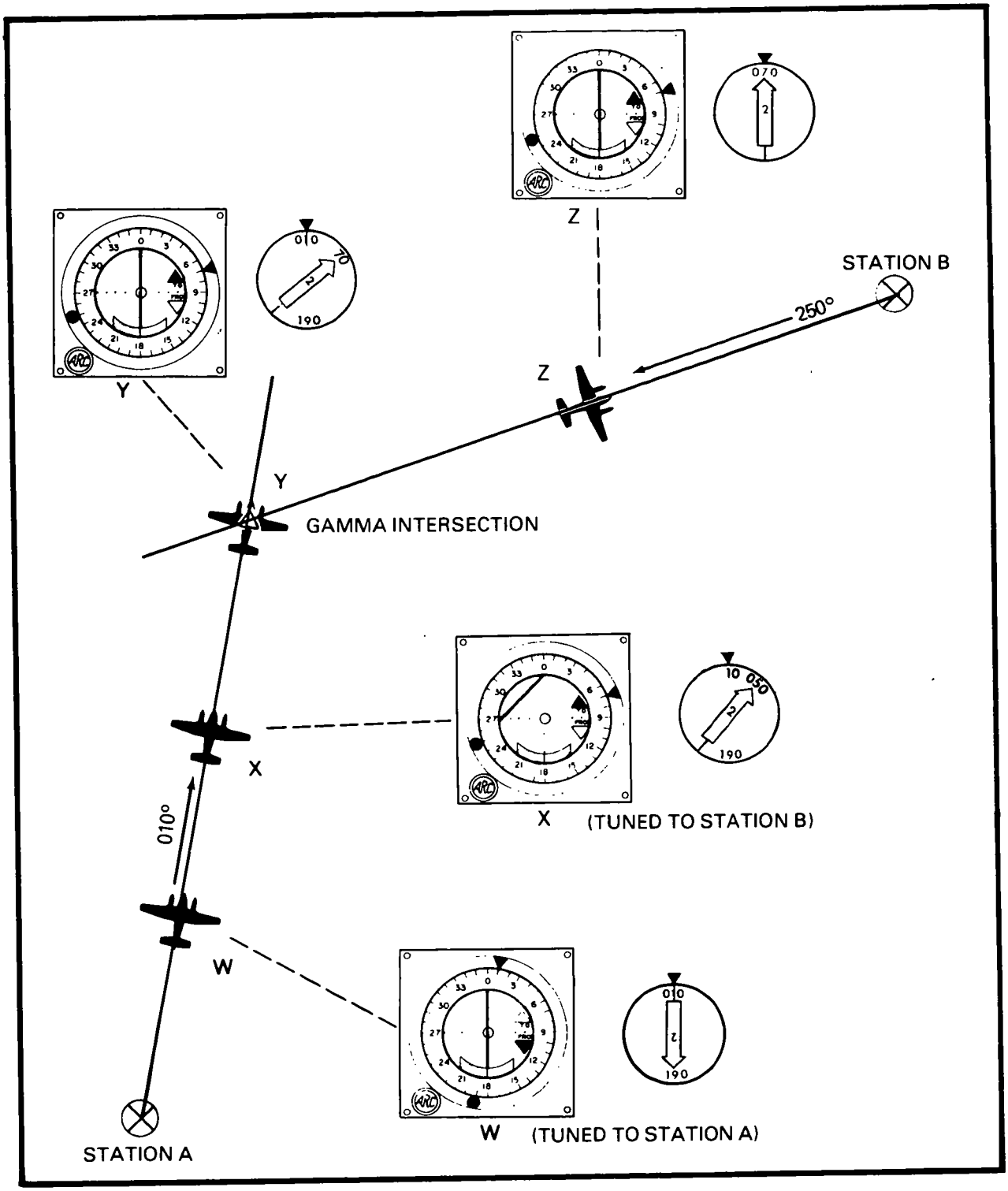


Figure 14-16. Position fixed at an intersection; course selector reading "TO."

identified (X, fig 14-16). The published radial for station B is 250°, but this radial is the direction *outbound* from B. Since it is desirable to go inbound, the course selector is set to 070°, the reciprocal of 250°. The resultant reading on the TO-FROM indicator is "TO" because a course of 070° will take the aircraft *to* station B. Station B is to the right of the aircraft from point X to Gamma intersection, but the needle deflects to the left. Since the course selector is set on the reciprocal of the published radial to produce the "TO" reading in the TO-FROM indicator, the needle deflects to the left. (Compare with the deflection described in "b" above.) The needle centers when the aircraft arrives over Gamma intersection (Y, fig 14-16), and remains centered inbound to station B (Z, fig 14-16) after the aircraft is placed on the 070° course.

d. If the aircraft in figures 14-15 and 14-16 were equipped with two VOR receivers, one would be tuned to station A to maintain the course and the other would be tuned to station B to determine the intersection.

14-12. COURSE INTERCEPTION

It is occasionally necessary to intercept a course that is located at some distance from the position of the aircraft. Several procedures can be applied, as explained below.

a. *From a Known Position—45° or 90° Interception.* At point A, in figure 14-17, the aircraft is flying a heading of 350° while crossing the 200° radial. The aircraft has been cleared to intercept Victor airway 13 (V-13), which is the 180° radial from the station. Since the position of the 200° radial with respect to the 180° radial to be intercepted is known, proceed as follows:

(1) Determine the direction of turn to intercept the 180° radial. This can be determined by setting the course arrow on the inbound course of 360°. This is the reciprocal of the published radial from the station (180°). With the course of 360° set in the course indicator, the deviation indicator will move to the right, indicating that the V-13 airway is to the right of the aircraft.

(2) Select a heading which will intercept the desired course at an angle of 45°. In this case, since the desired course to the station is 360°, a heading of 045° would intercept the course at a 45-degree angle.

Note. **The standard interception angle is 45°; however, others may be used. If ATC requests the aviator to "expedite," a 90-degree interception angle should be used.**

(3) Turn to the selected heading and set the course arrow on the desired course—360°.

(4) Turn to the inbound heading of 360° when the course deviation indicator

centers (B, fig 14-17). The bearing pointer of the RMI will indicate 360° at this time.

(5) Use course maintenance procedures to fly to the station on V-13.

(6) Procedure (2) above can be changed to intercept the track at a 90-degree angle (C, fig 14-17), if necessary, to reach the track in the least possible time.

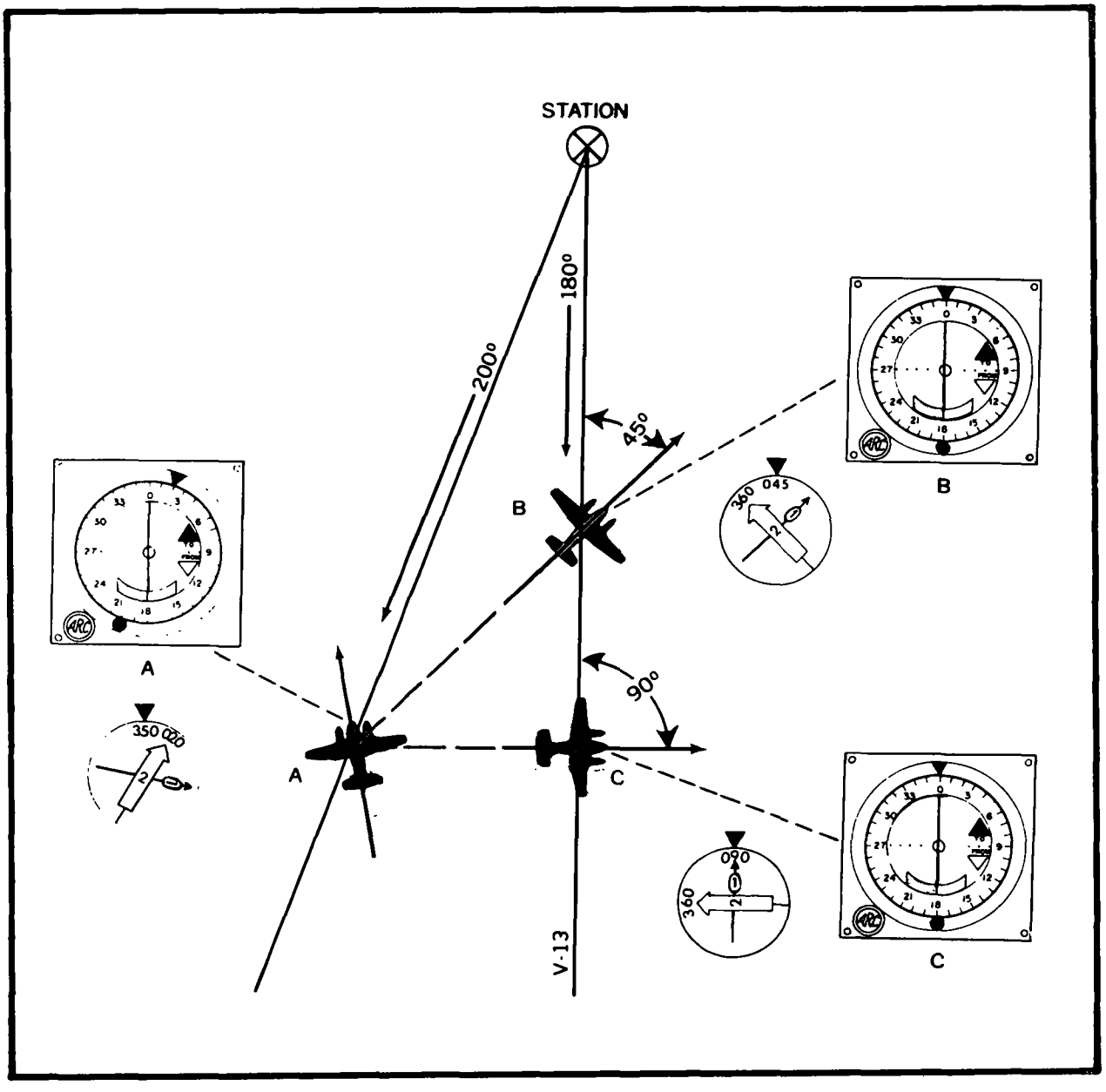


Figure 14-17. Course interception at 45° or 90° from a known position (VOR).

b. *From a Known Position—Double-the-Angle Interception.* The double-the-angle method of intercepting a desired course from a known position consists of the following procedures (fig 14-18).

(1) Determine the angular difference between the radial on which the aircraft is presently located and the radial which represents the desired course. At point A of figure 14-18, the aircraft is on the 150° radial and the desired course to the station is 360°. (This is the 180° radial, so the angular difference is 30°.)

(2) Double the angular difference and this will give a desirable interception angle. In this case, the interception angle will be 60°.

Note. When using this procedure, initial interception angles of less than 20° are usually not practical. Also, an interception angle of 90° is the maximum; thus, an angle greater than 45° would not be doubled.

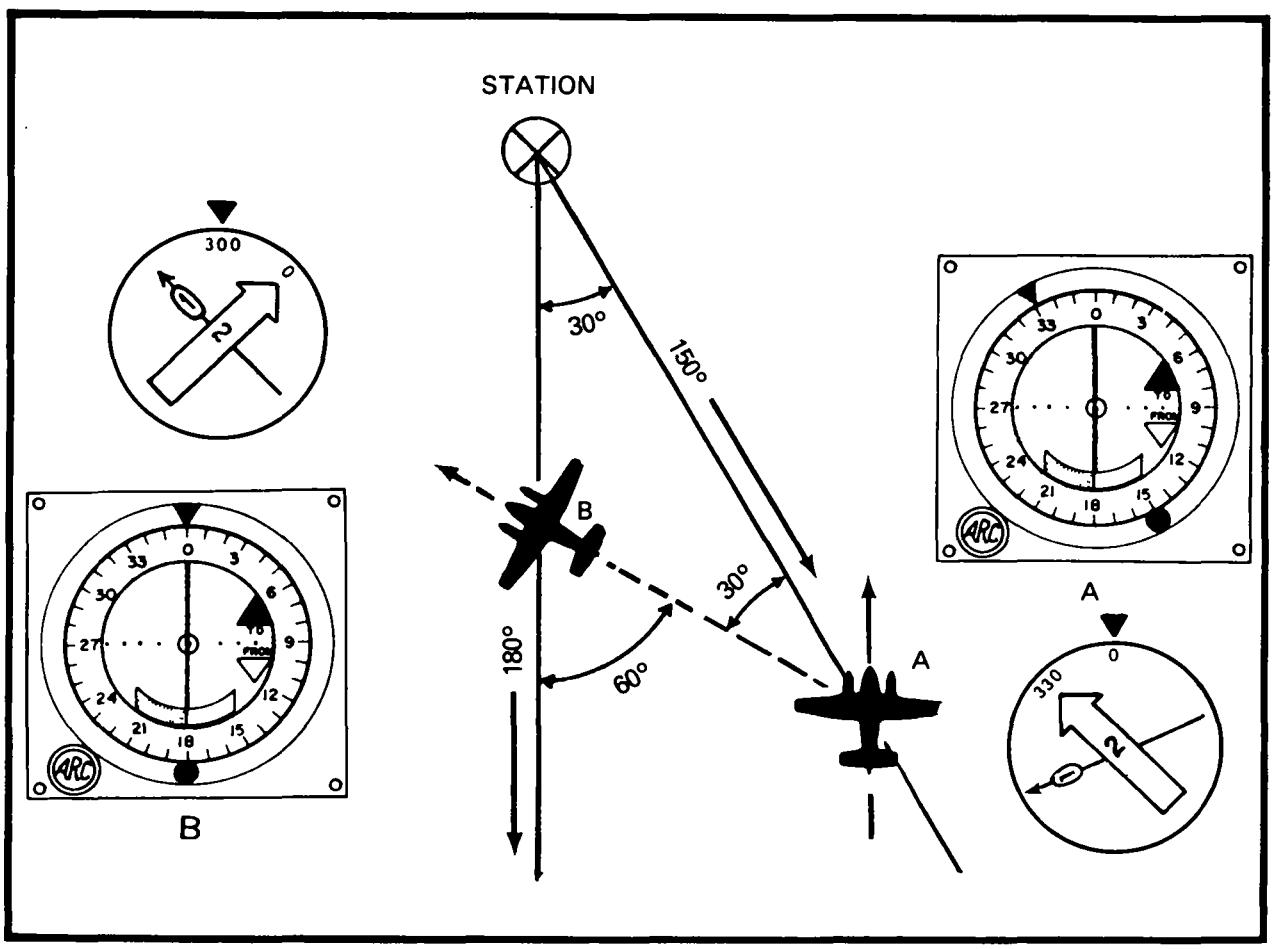


Figure 14-18. Double-the-angle course interception from a known position (VOR).

(3) Select the heading which will cause the aircraft to intercept the desired course at the desired interception angle. In this case, a heading of 300° will intercept the 360° course at the desired 60-degree angle.

(4) Turn the aircraft to the selected heading and reset the course selector for the 360° course.

(5) At the time the deviation indicator centers (B, fig 14-18), the aircraft has reached the course. The bearing pointer of the RMI will indicate 360°.

Note. **When using this technique, the leg flown to intercept (from point A to point B) is equal in length to the leg remaining to the station (from point B to the station). Consequently, the time required to fly the interception leg (point A to point B) is the approximate time remaining to fly to the station from point B.**

c. *Leading the Needle.* If the turn onto the intercepted course is delayed until the deviation needle is fully centered, there is the risk of overshooting the course. If the turn to the heading of the course is started too soon, the aircraft may roll out of the turn short of the course. During initial course interception or reinterception, the technique of leading the deviation indicator must be used. The rate of movement of the deviation indicator and the size (degree) of the interception angle must be considered in determining when to start the turn in order to place the aircraft on the course.

d. *Interception of a Course From an Unknown Position.* The requirement exists to intercept a specific course at a time when it is uncertain which radial the aircraft is positioned on. A simple method to become oriented with respect to a desired track is as follows:

(1) From the present heading of the aircraft, turn the shortest way to a heading which is parallel to either the course heading or its reciprocal. (The station has previously been tuned and identified.)

(2) While turning ((1) above), set the course selector to the course or its reciprocal depending upon which heading the aircraft is flying.

(3) After rolling out of the turn ((1) above), observe the deflection of the deviation indicator. The course lies to the same side as the indicator is deflected. The TO-FROM indicator will now indicate if the station is ahead of or behind the aircraft.

(4) Turn toward the course to a heading which will intercept the course at an appropriate angle.

Note. **This procedure is true only when the heading of the aircraft is within 90° of the course indicated by the course arrow.**

[redacted]

a. In most situations, an aircraft will be flying in a region where two VOR stations are within reception distance. The position of the aircraft and an estimate of time and distance to either station may be determined by plotting the course or bearing to each station on a navigation chart. The aircraft will be located at the position where the courses or bearings cross.

b. In some isolated cases, it may be necessary to estimate the time or distance to a station by using the signal from a single station. One technique of doing this is pointed out in the note in paragraph 14-12b.

c. A different method is illustrated in figure 14-19. The aircraft is inbound to the station on the 200° radial. To estimate the time and distance to this station, proceed as follows (fig 14-19):

(1) Turn the aircraft through 80° (left in fig 14-19).

(2) Move the course selector 10° (from 020° at point A to 030° at point B) to a known radial ahead of the aircraft.

(3) Wait for the deviation indicator to center and take a time check (e.g., 1412:50).

(4) Move the course selector an additional 10° (from 030° at point B to 040° at point C).

(5) Wait for the deviation indicator to center and take a second time check (e.g., 1414:55, or 2 minutes and 5 seconds elapsed during the 10° bearing change).

(6) Turn inbound to the station (D) and estimate the time to the station by applying the following formula (data taken from situation in fig 14-19):

$$\text{Time Remaining to Station} = \frac{\text{Minutes Flown} \times 60}{\text{Degree Change}} = \frac{\text{Seconds Flown}}{\text{Degree Change}}$$

$$\text{Time Remaining to Station} = \frac{2\frac{1}{2}\text{ Minutes} \times 60}{10^\circ} = \frac{125\text{ Seconds}}{10^\circ} =$$

12.5 Minutes

Note. **If aircraft is turned 80° right ((1) above), move course selector from 020° to 010° in (2) above and from 010° to 360° in (4) above.**

(7) The approximate distance to the station may be estimated by using the following formula:

$$\text{Distance to Station} = \frac{\text{True Airspeed} \times \text{Minutes Flown}}{\text{Degree Change}}$$

(8) Substituting the data from figure 14-19—assume the true airspeed is 120 knots—

$$\text{Distance to Station} = \frac{120 \times 2\frac{1}{2}}{10} = 25\text{ Nautical Miles}$$

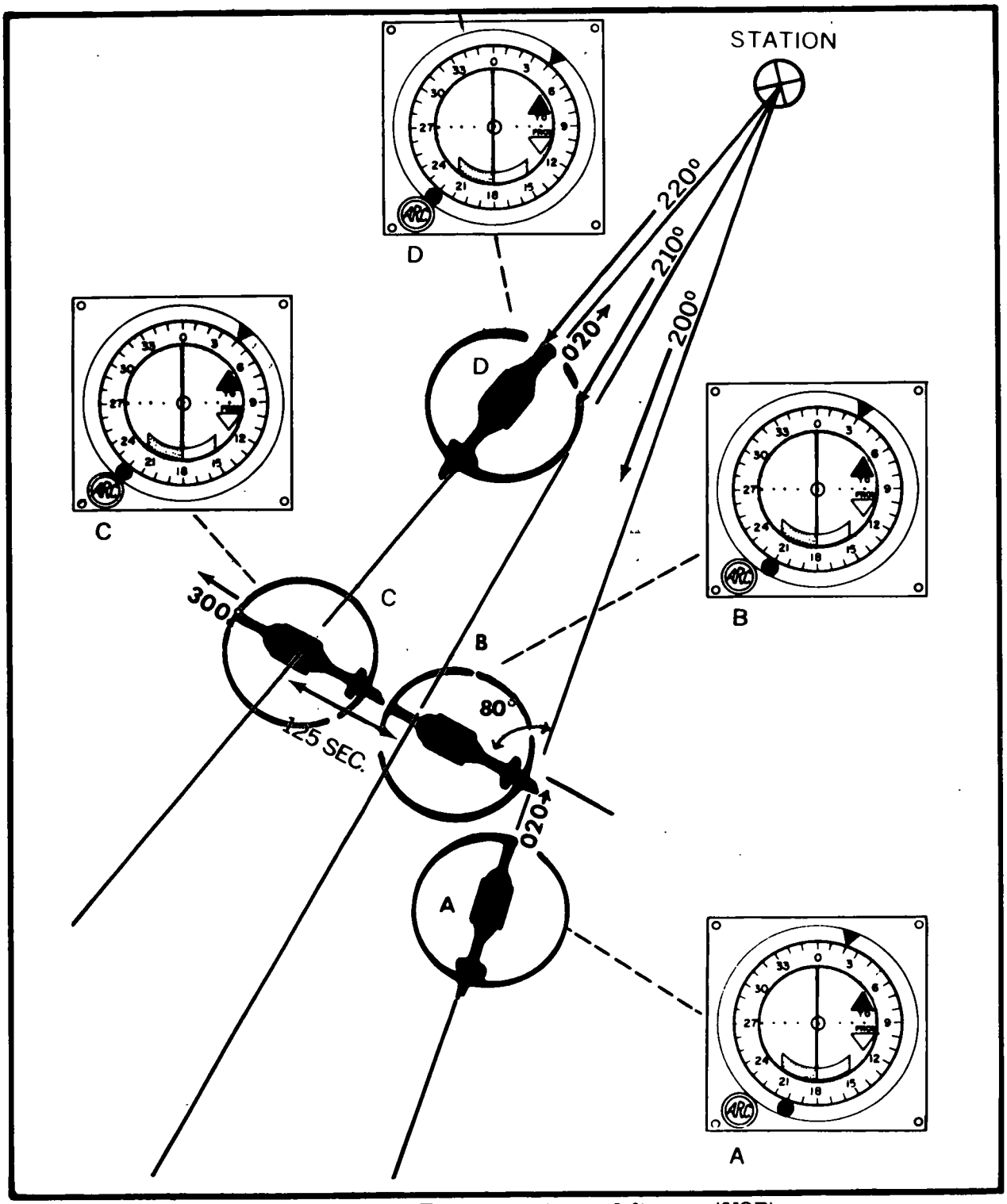


Figure 14-19. Estimating time and distance (VOR).

Note. **Seconds must be changed to fractional or decimal parts of a minute.**

d. The following limiting factors should be kept in mind when applying the above time-and-distance formulas:

(1) They are based on the assumption that a 1-degree angle is 1-mile wide 60 miles away from the station. This is an approximation.

(2) They do not take into account wind conditions that may cause ground-speeds to vary considerably on headings which differ by 90°.

(3) To determine time-distance required, the aircraft must turn so that it will fly abeam the station during the time required for the aircraft to fly through a 10-degree change in the course selector reading.

(4) The bearing change selected (change in the course selector setting) may vary from 5° to 15°. Ten degrees is used as a mathematical convenience in the above problems.

Section III. RECEIVER CHECKS

[illegible] GENERAL

VOR receivers and their associated indicators (e.g., ID-453) must be checked periodically for accuracy. There are several types of checks which can be performed to insure equipment accuracy. In performing these checks, current data for designated station frequencies, specific VOR radials, and station identifications is contained in current navigational publications.

[illegible] RADIATED TEST SIGNAL

Equipment installed at many airports transmits a continuous test signal receivable at any point on the airport. Although designed primarily as a ground test system, this equipment is also usable at relatively low altitudes in flight over the airport. The procedure for using the radiated test signal (VOR receiver testing facility (VOT)) to check receivers is as follows:

a. Tune the frequency of the VOT.

b. Listen for the proper identification; i.e., either a continuous series of dots or a continuous 1,200-cycle tone.

c. Check for the disappearance of the warning flag.

d. Set the course to either 180° or 360°.

e. Check the reaction of the TO-FROM indicator. If the course is set on 180°, the indicator should read "TO." If the course arrow is set on 360°, the indicator should read "FROM."

f. Check the course deviation indicator. It should be centered. If the needle is not centered, rotate the course selector until the indicator centers. If the course selector does not have to be rotated more than 4° in order to center the needle, the equipment is within tolerance for flight under IFR. If the needle will not center within a 4-degree tolerance, the equipment is unreliable for flight under IFR. Should the VOR receiver be coupled to a radio magnetic indicator, the bearing pointer will indicate 180° regardless of the course selector setting.

[redacted]

Not all airports have equipment for radiated test signals (VOT). However, many airports have VOR stations situated nearby from which selected radials can be used for checkpoints. Location of the ground check radial may be obtained from tower or airfield operations personnel. In the illustration (fig 14-20), the 120-degree radial from a station passes directly over the end of runway 27. An exact spot is marked on this runway. The aircraft is taxied to this spot and the receiver check is performed in the following manner:

a. Tune to the frequency of the station.

b. Listen for the correct station identification.

c. Check for the disappearance of the warning flag.

d. Set the course selector to the specific radial for the check.

e. Check the reaction of the TO-FROM indicator. It should indicate FROM.

f. Check the course deviation indicator for a centered position. Plus or minus 4° tolerance is allowed on the course selector setting for centering the needle. If movement of the course selector within 4° of the published radial will cause the deviation needle to center, the equipment is usable. Equipment that does not meet these tolerance limits is unreliable for flight under IFR.

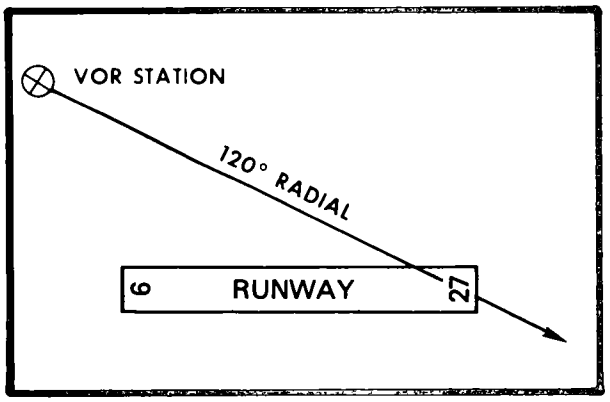


Figure 14-20. Ground receiver check (VOR).

[redacted]

a. At airports where radiated test signals (VOTs) or other ground check radials have not been established, an airborne check radial may exist. Airborne checks are performed like ground checks

except that an airborne checkpoint is specified instead of a designated spot at the airport. *For example,* if a prominent water tower exists within a few miles of the VOR station, a certain radial can be selected which passes over this tower. As the aircraft flies over the tower, the accuracy of the equipment can be checked. A published airborne check over the tower may appear in navigational publications as "DALLAS, TEXAS, (Love Field)—213°, over striped water tower on Loop 12 (highway) approximately 2.6 miles east—northeast of Love Field."

b. To perform the airborne check—

(1) Tune and identify the Dallas, Texas, VOR.

(2) Set the course on 213° and check for a "FROM" reading.

(3) Fly over the water tower described.

(4) When over the water tower, check the deviation indicator for a centered position with a "TO" indication. If the needle is within 6° of center, or if a course selector movement of 6° or less from the published radial will cause the needle to center, the equipment is within tolerance. Equipment that does not meet these tolerance limits should not be used for flight under IFR.

[redacted]

If an aircraft is equipped with dual receivers, one receiver may be checked against the other. If receivers are within 4° of each other, both may be considered reliable. To perform this check—

a. Tune and identify the same VOR station with both VOR receivers.

b. Using dual course indicators (ID-453 or equivalent), rotate the course selectors of each until the deviation indicator is centered.

c. Check to determine that the TO-FROM indicators on each instrument are in agreement.

d. Check the course settings. These settings must be within 4° of each other. If receivers do not meet these limits, one or both are unreliable. Each will have to be checked with a VOT or a ground checkpoint to determine if it is within the allowable tolerance for flight under IFR.

[redacted]

In a location where no receiver checks are published, a checkpoint from a nearby VOR station may be established. To accomplish an unpublished receiver check—

a. Select a VOR radial that lies along the centerline of an established VOR airway.

b. Select a prominent ground point along the selected radial, preferably more than 20 nautical miles from the VOR ground facility, and maneuver the aircraft

directly over the checkpoint at a reasonably low altitude.

c. Note the VOR course indicated by the receiver when over the ground point. (The maximum permissible variation between the published radial and the indicated course is 6°.)

14-20. [illegible]

At the same time that the VOR receiver is checked for accuracy, the deviation indicator can be checked for sensitivity. The face of the course indicator (ID-453) (fig 14-21) is graduated in 2-degree intervals. Moving from center to either side, the edge of the small circle is 2° and each dot (alined horizontally) represents 2°. When the deviation indicator is fully deflected to one side, the aircraft is off the selected course by at least 10°. Consequently, if the receiver is checked for a centered indicator with the course selector set on a given radial—*for example* 140° (A, fig 14-21)—a full swing of the indicator can be checked by setting the course selector on 130° (B, fig 14-21) and then on 150° (C, fig 14-21). Normally, a 10-degree change in the course selector setting will cause a full scale movement of the course deviation indicator. However, in all cases a full scale swing (10°) should require no more than an 8- to 12-degree movement of the course selector.

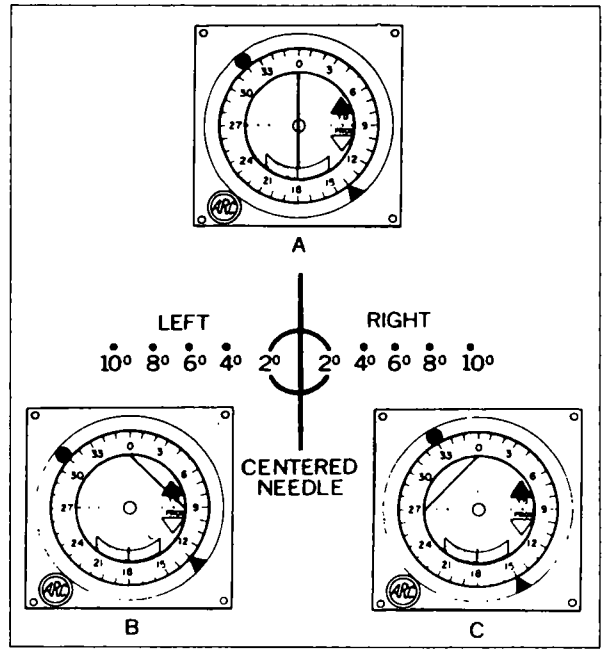


Figure 14-21. Course deviation indicator sensitivity check.

Note. **Pertinent information for VOR receiver checks should be verified from current navigational publications and regulations. This information is subject to change.**

Section IV. VOR STATION CLASSIFICATION

14-21. CLASSIFICATION BY GENERAL TYPES

The classes of VOR stations are—

a. *T (Terminal)*. (T) VOR.

b. *L (Low Altitude)*. (L) VOR.

c. *H (High Altitude)*.(H) VOR.

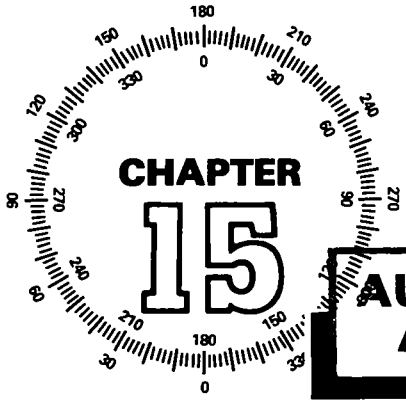
[redacted] BY RECEPTION

Stations are also classified by their interference-free reception capabilities with respect to distance and altitude. This classification is the basis for establishing the interference-free reception range of transmitter frequencies. The following data shows station classification with normal usable radial distances and altitudes:

[redacted]	Altitudes	Distances (NM)
T	12,000 ft and below	25
L	Below 18,000 ft	40
H	Below 18,000 ft	40
H	14,500 ft - 17,999 ft	100*
H	18,000 ft - FL 450	130
H	Above FL 450	100

*Applicable only within the conterminous United States.

Note. **Classification of stations is subject to change. Current operational publications should be consulted for latest information.**



CHAPTER 15

AUTOMATIC DIRECTION FINDER (ADF) AND MANUAL LOOP PROCEDURES

Section I. CHARACTERISTICS AND COMPONENTS

15-1. GENERAL

The *radio direction finder* (RDF), sometimes referred to as a *radio compass,* is a radio receiver used to determine the bearing to a radio transmitter from the aircraft. This receiver has a loop antenna that is used to determine this bearing. When the loop antenna is placed in the signal pattern of a radio transmitter, no signal will be heard when the plane of the loop is perpendicular to a line from the aircraft to the transmitter. This position of the loop is called the *null.* Navigation with the radio direction finder uses the null for determining the direction to the transmitting facility. This can be done manually be using automatic direction finder procedures (para 15-4 through 15-21) or loop procedures (para 15-22 through 15-26).

15-2. ARMY ADF SETS

The Army uses several different receivers, usually referred to as *ADF receivers,* for radio direction finding. The frequency

spectrum of these receivers is from .19 megahertz (MHz) (190 kilohertz (kHz)) to 1.75 MHz (1750 kHz). In this frequency range are the nondirectional radio beacon (NDB) and the low/medium frequency (L/MF) radio ranges. Their classification and usable radii are as follows:

Nondirectional Radio Beacon Usable Radii		
Class	*Power (watts)*	*Distance (nautical miles (NM))*
(L) Compass Locator	Under 25	15 NM
MH	Under 50	25 NM
H	50 - 1999	50 NM
HH	2000 or more	75 NM

Note. Service range of individual facilities will be less than stated when flight is conducted at low altitudes.

For navigating by RDF it is best to use nondirectional radio beacons. These beacons are listed in flight information publications and are designated on air navigation charts. They are designed and maintained for air navigation. For best results, they should be used only within the usable distances as listed in the chart above. If the airborne RDF receiver and associated equipment are not operating at their optimum level, the usable distances may be further reduced. Radio beacons are sometimes subject to fading signals and signal interference from distant stations at night. During periods of thunderstorm activity, the aviator may find the atmospheric static will interfere with tuning and identifying a radio beacon and will cause erratic operation of the bearing needle. Commercial broadcast stations should be used only if an NDB is not available. These stations have irregular hours of operation; do not broadcast their identification at frequent or regular intervals; are subject to signal interference from other stations; and frequently have highly directional signal patterns that may cause unreliable indications while using ADF procedures. If a commercial broadcast station must be used, select a station that is designated on an air navigation chart.

15-3. ADF RECEIVER COMPONENTS

Components of an ADF receiver are:

a. The receiver.

b. A loop antenna.

c. A sensing antenna.

d. The radio control panel.

e. The indicator, which is used to solve RDF problems for navigational purposes. The most commonly used indicator, the radio magnetic indicator (RMI) (fig 15-7), has a rotating compass card that displays the magnetic heading of the aircraft under the index at the top of the dial and needles or bearing pointers. When the signal from an ADF receiver is switched to one of these needles, it will aline itself on a heading on the compass card corresponding to the magnetic course to the station being received.

Section II. AUTOMATIC DIRECTION FINDER FLIGHT PROCEDURES

15-4. ORIENTATION PROCEDURE

Set the RMI function switch to the ADF position. This will cause the No. 1 bearing pointer to respond to the signals from the ADF receiver. Tune the receiver and identify the desired radio station. Insure that the receiver is tuned to receive the strongest signal possible. This is accomplished by adjusting a tuning meter to its greatest sensitivity or by determining the best audio signal with the ear. Weak reception or off-frequency tuning of the signal will cause the bearing pointer to fluctuate or indicate an incorrect magnetic bearing to the station. Correct tuning of the receiver may be made difficult by atmospheric static being received. By switching to the antenna (ANT) position on the receiver, a clearer signal can be received for tuning using the audio signal. When using this procedure, be sure to switch back to COMP/ADF position after tuning is completed. The response of the bearing pointer to the signal may be tested by moving it left or right on the RMI with the LOOP switch to determine if it will return to the original bearing when the LOOP switch is released. After tuning the radio receiver and identifying the station, ascertain that the function switch on the radio control panel is in the COMP/ADF position and that the RMI function switch is in the ADF position. If the ADF is being used as the primary means of navigation, the receiver volume should be adjusted so that the signal is just barely audible. If during flight the signal is no longer heard, the aviator is alerted to possible failure of the receiver. The receiver itself and the RMI have no warning devices to indicate failure of the receiver. The bearing pointer may remain in what appears to be a normal operating position and a failure is not detected until changing the desired course. During flight in heavy precipitation or near a thunderstorm where lightning is occurring, the indications of the bearing pointer may become so erratic that accurate navigation cannot be accomplished. If the flight is being conducted under instrument flight rules (IFR), the air traffic controller should be advised that the flight cannot be continued using the ADF receiver as the primary means of navigation. The bearing pointer always indicates the magnetic bearing to the station. If the requirement exists to proceed to the radio station, the aircraft should be turned toward the bearing pointer until it is alined with the index at the top of the RMI. The aviator can use "homing" procedures to the station by keeping the bearing pointer alined with the index or can track to the station along a desired course, applying wind drift corrections. Using homing, the aircraft will fly a curved track to the station if any crosswind exists (fig 15-1). When maintaining a desired course, the aircraft's ground track to the station will be a straight line (fig 15-2). Air traffic control (ATC) clearances that specify "direct" to a named radio facility require that a direct course be maintained to that facility.

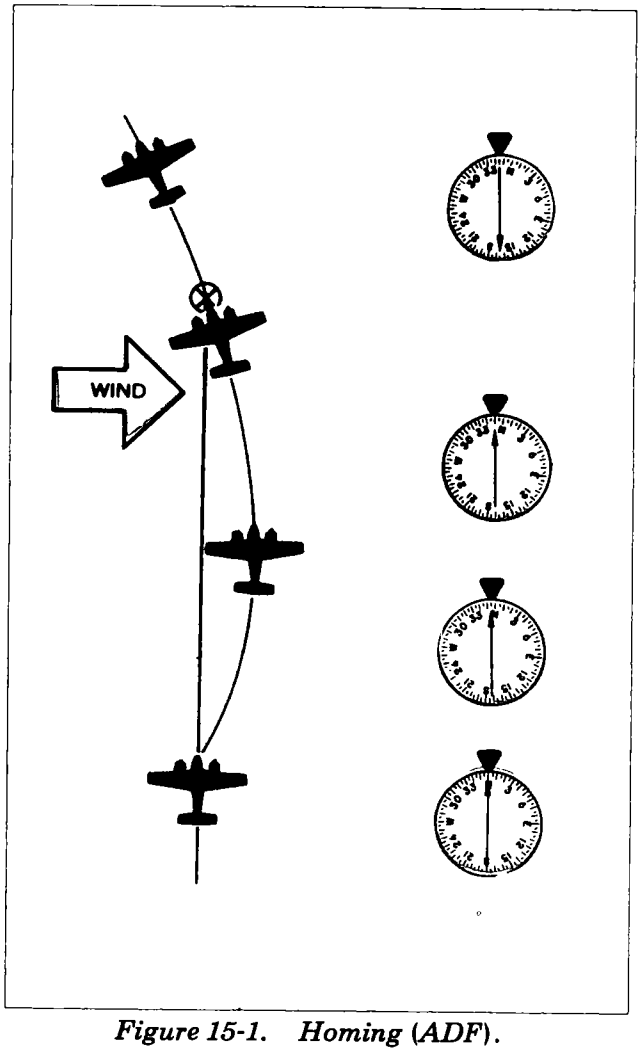


Figure 15-1. Homing (ADF).

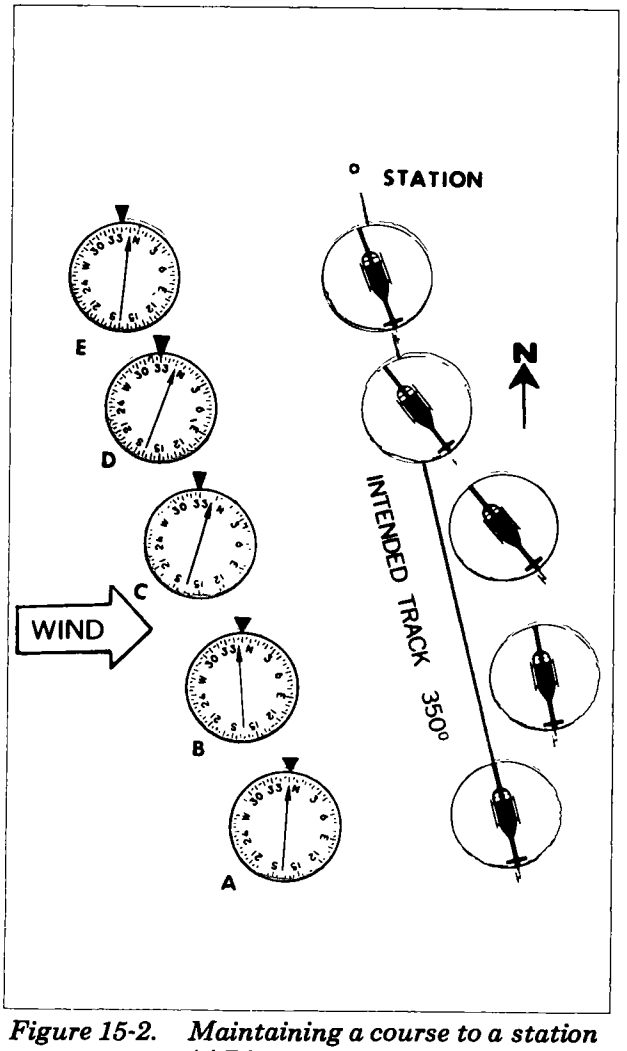


Figure 15-2. Maintaining a course to a station (ADF).

15-5. MAINTAINING A COURSE TO A STATION

The procedures for maintaining a course to a station are illustrated in figure 15-2.

a. *Position A.* At position A, the aircraft is on course with the bearing pointer alined with the heading index and the magnetic course of 350°.

b. *Position B.* At position B, the bearing pointer is deflected 5° to the left of the course, indicating that the aircraft has been blown to the right of course. To return to the course, a drift correction must be applied to the left of the aircraft heading. This initial correction should be 20° for aircraft flying an airspeed of 90 knots (kt), or above, and 30° for aircraft flying at airspeeds below 90 knots. If these correc-

tions do not readily bring the aircraft back to course, larger corrections may be used.

c. *Position C.* At position C, 20° left correction has been applied to a heading of 330°. The bearing pointer will continue to indicate 5° left drift throughout the turn.

d. *Position D.* At position D, the aircraft has returned to course and the bearing pointer indicates the magnetic heading of the desired course.

e. *Position E.* At position E, the heading of the aircraft is 340°. One-half of the drift correction has been removed. This heading should compensate for the wind effect and allow the aircraft to remain on course. If this correction is too much, the aircraft will fly off course to the left. To correct for this condition, return the aircraft to the heading of the desired course and allow the aircraft to drift back on course (bearing pointer reads 350°). When on course, apply less drift correction than before and determine if the aircraft will remain on course. These procedures will be followed until a heading has been determined that will maintain the aircraft on course.

15-6. STATION PASSAGE

Passage of the station will be indicated by the bearing pointer moving from the magnetic heading of the course to a magnetic heading which is the reciprocal of the course. If the aircraft passes directly over the station, the bearing pointer will rapidly reverse its position as stated above. If the aircraft passes to one side of the station, the bearing pointer will move more slowly and give an indication on which side the station is being passed. As the aircraft passes the station, the bearing pointer will move to a magnetic bearing which is somewhere near the reciprocal of the course. For timing purposes, station passage occurs when the bearing pointer passes through a position 90° to the desired course.

15-7. MAINTAINING A COURSE FROM A STATION

When maintaining a course from a station, the bearing pointer will be indicating a magnetic bearing which is the reciprocal of the course. This indicates that the aircraft is flying away from the station. If the bearing pointer later begins to point to a magnetic bearing which is to the left of the course reciprocal, the aircraft has been blown to the right of the course by the wind. The aircraft can then be returned to the course and the course maintained by using the procedures described in paragraph 15-5. The tail of the bearing pointer may be used to determine the position of the aircraft in relation to the desired course; however, it is nondirectional and corrections must be made in the opposite direction to the tail of the needle.

15-8. POSITION FIX

While maintaining a course, a requirement may exist to determine a fix which is located along that course. This may be an

intersection on an airway chart, an approach chart, or some point along the course request to be identified by ATC. When another navigational receiver, VHF omnidirectional range (VOR) or instrument landing system (ILS), is being used to maintain the desired course, the ADF receiver may be tuned to the L/MF station from which the reporting point is to be identified. In figure 15-3 the aircraft is maintaining a course of 090°. The fix is formed by a course to the beacon of 120° and the present course of 090°. When the bearing pointer indicates a magnetic bearing of 120°, the aircraft is over the fix. For position fixing when the ADF is being used to maintain a course, two ADF receivers are required or alternate tuning of the one receiver from one station to the other is required. This procedure is necessary to insure that the aircraft does not drift off course while identifying the fix.

15-9. COURSE INTERCEPTION INBOUND

Course interceptions inbound to a station are illustrated in figure 15-4. At point A, the aircraft is maintaining a course of 050° to the beacon. A requirement arises to intercept and track inbound on a course of 080°. The aviator can either visualize that the 080° course is to the left or use the parallel method of determining the position of the aircraft in relation to the 080° course. Using the parallel method, the aircraft is turned to a heading of 080°. The bearing pointer is observed to the left of the aircraft heading. This means that the 080° course is to the left. The standard interception angle (45°) is applied and a left turn to a heading of 035° is made. A smaller interception angle may be used if the difference between the present course and the desired course is

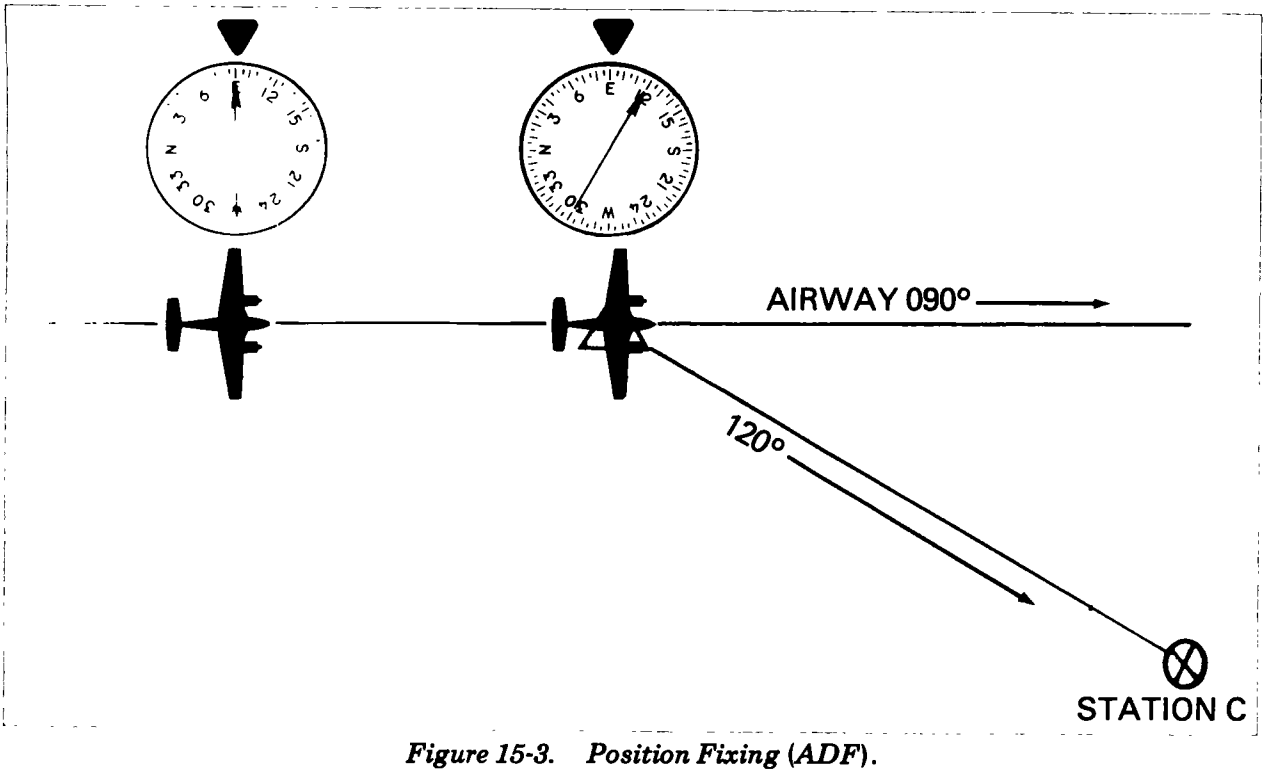


Figure 15-3. Position Fixing (ADF).

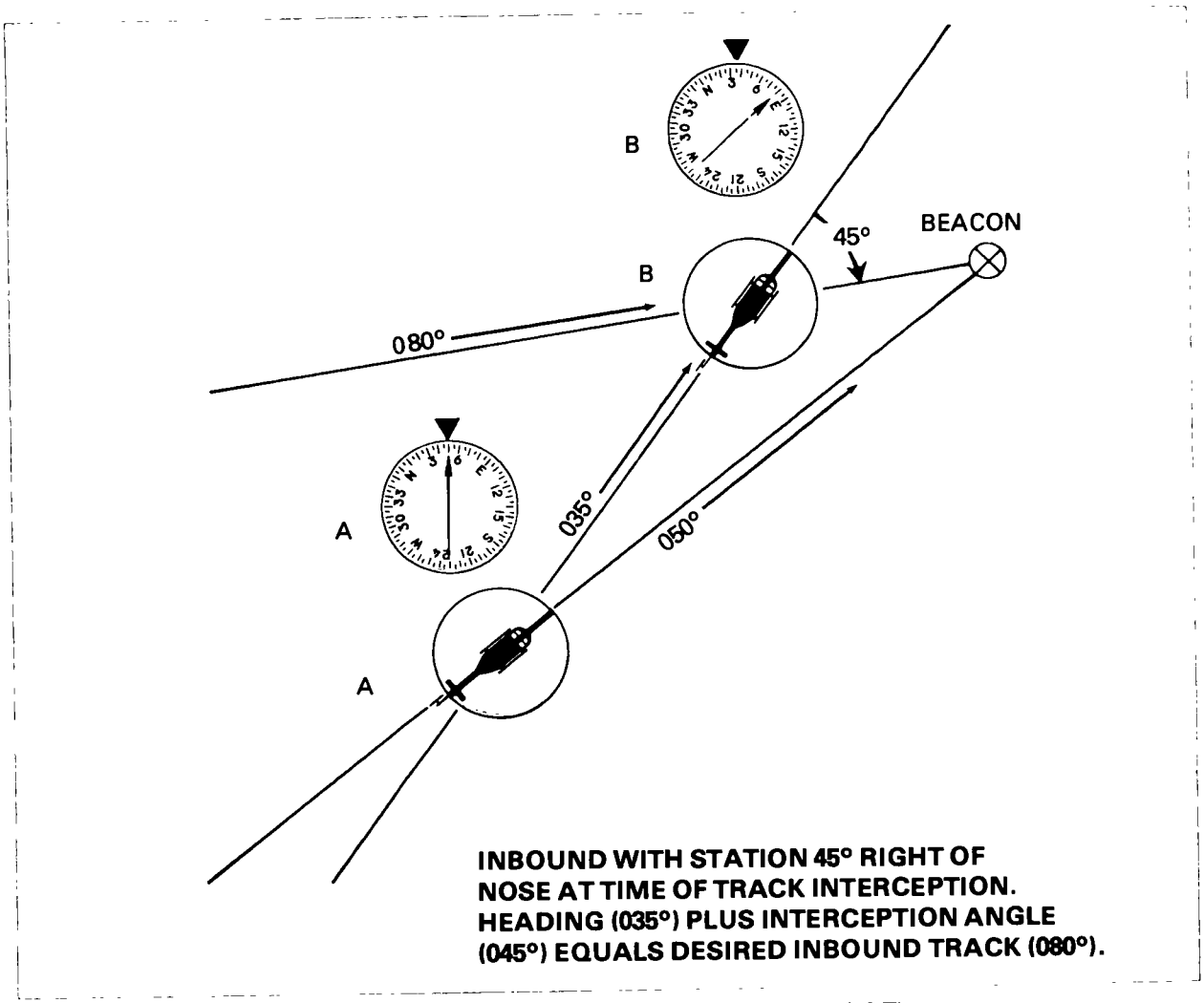


Figure 15-4. Course interception inbound (ADF).

20° or less or when the position of the aircraft is known to be close to the station. When these conditions exist, the intercept angle should be double the difference between the courses so as to insure course interception without delay. When the bearing pointer approaches the bearing of 080°, a turn to this heading should be made, adjusting the degree of bank so as to roll out on the inbound course (point B). Determination of when to start this turn will be based on the following factors:

a. *Movement Speed of the Bearing Pointer.* A rapid movement of the bearing pointer means that the aircraft is close to the beacon, and the turn must be begun prior to the bearing pointer's reaching the desired course. A delay will result in overshooting the desired course. A slow movement of the needle requires that the turn to course be delayed until the bearing pointer is close to the desired course.

b. *Speed of the Aircraft.* The speed of the aircraft requires that the turn be

delayed or started sooner to avoid undershooting or overshooting the desired course.

c. *Angle of Intercept.* Large angles of intercept require that the turn be started earlier than for small angles. Once the aircraft has rolled out of the turn, the procedures for maintaining a course as outlined in paragraph 15-5 will be followed.

[redacted]CEPTION

In figure 15-5, an aircraft at point A is maintaining a course of 230° from a beacon. The requirement arises to intercept and maintain a course of 260° from the beacon. Either the visualization or the parallel method discussed in paragraph 15-9 can be used to determine the direction of turn to intercept the desired track. If the parallel method is used, the aircraft is turned to a heading of 260°. The bearing pointer indicates to the right of the reciprocal of the desired course (080°). To intercept the 260° course, the aircraft is turned to a heading of 305° (45° intercept angle). When the bearing pointer approaches the reciprocal of the course (bearing of 080°), a turn is begun to roll out on the 260° course from the beacon (point B). Determination of when to start this turn may be made using the factors set forth in paragarph 15-9. After the turn has been completed, the procedures for maintaining a course, as outlined in paragraph 15-5, will be followed.

[redacted] DETERMINATION OF TIME AND DISTANCE FROM A STATION (ADF)

To compute the time and distance to an L/MF station, tune and identify the station and turn the aircraft until the

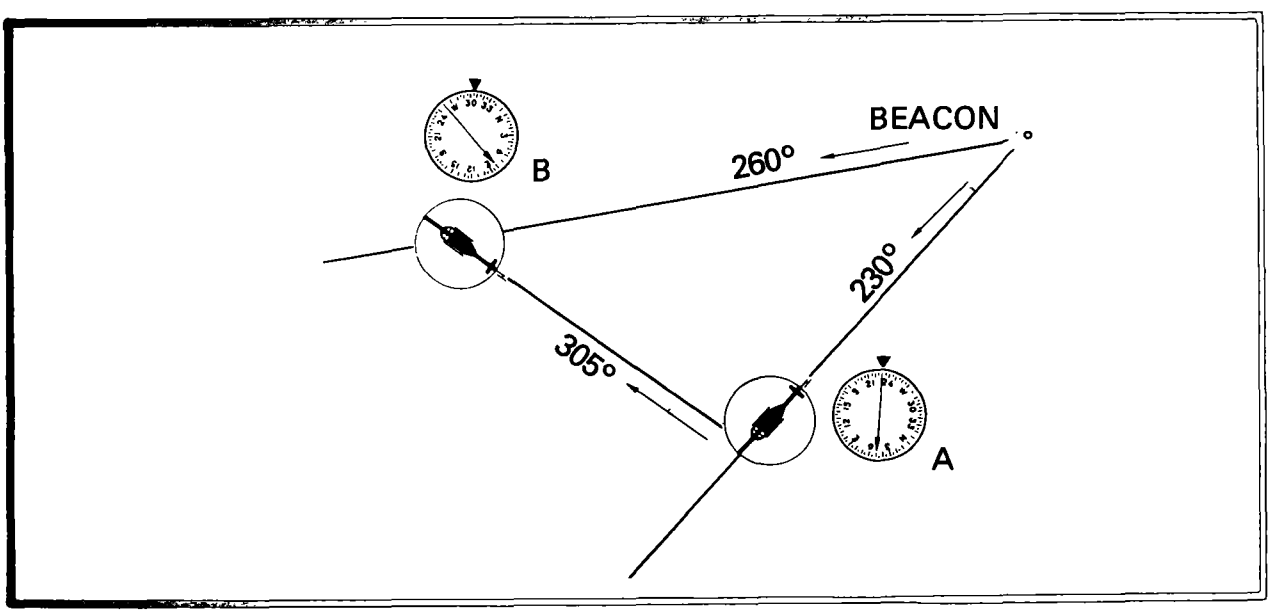


Figure 15-5. Course interception outbound (ADF).

bearing pointer is displaced 90° to the aircraft heading (90° index of the RMI). Note the time and maintain this heading. When the bearing pointer moves 10° from the 90° index, note the time that has elapsed and apply the following formulas:

$$\frac{\text{Time in seconds between bearings}}{\text{Degree of bearing change}} = \text{Time in minutes from the station}$$

Example:

$$\frac{120 \text{ seconds}}{10°} = 12 \text{ minutes from the station}$$

$$\frac{\text{*True airspeed}}{60} \text{ X minutes from the station} = \text{nautical miles from the station}$$

***If known, groundspeed should be substituted for TAS.**

Example:

$$\frac{120 \text{ kts}}{60} \times 12 = 24 \text{ NM from the station}$$

Section III. AUTOMATIC DIRECTION FINDER FLIGHT PROCEDURES USING RELATIVE BEARINGS

15-12. RELATIVE BEARING

When the slaved gyro compass of the RMI system fails and the L/MF radio station is the only navigational aid (NAVAID) available, ADF procedures using relative bearings must be used. For the purpose of this discussion, it will be assumed that the compass card remains motionless (referred to as "fixed card") with the figure of 060° under the index at the top of the RMI. The position of the bearing pointer will no longer indicate a magnetic bearing. The indication of the bearing pointer will be read in relation to the index at the top of the RMI. The index represents the nose of the aircraft. For this

reason, the bearing is called a *relative bearing*. The relative bearing to the L/MF station is measured clockwise from the nose of the aircraft to the position of the bearing pointer. Although usually referred to as a relative bearing, the position of the bearing pointer may be referred to as being so many degrees left or right of the nose. For example, a relative bearing of 270° may be referred to as a bearing of 90° left of the nose of the aircraft. In figure 15-6, the relative bearing to the beacon at positions A, B, and C is 060°; i.e., the beacon is 60° right of the nose of the aircraft. To determine the magnetic course to the beacon from each position, add 60° to the magnetic heading of the aircraft as read from the magnetic compass.

15-13. ORIENTATION (FIXED CARD)

The procedure for ADF orientation using relative bearings is as follows:

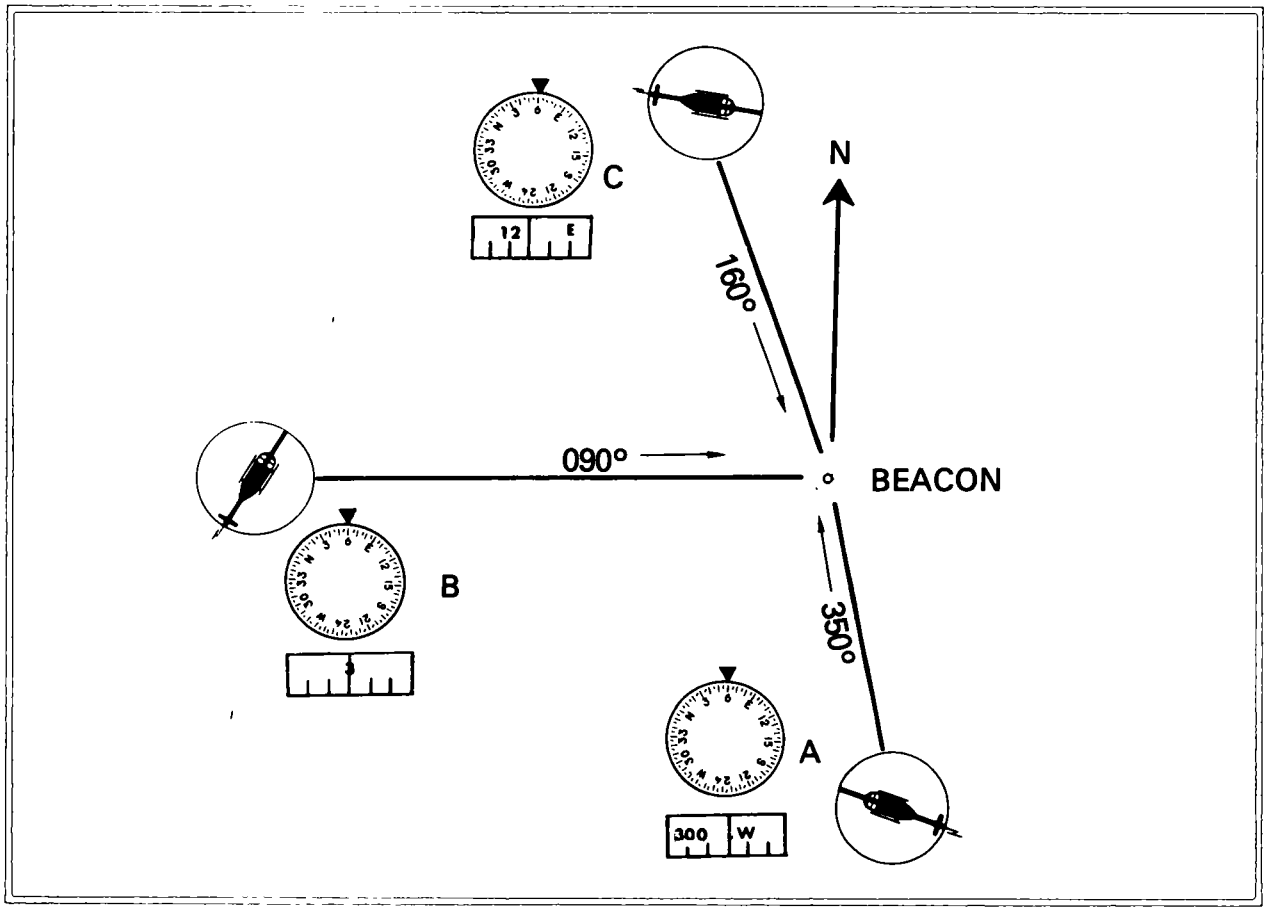


Figure 15-6. Relative bearing of 060°, with three different aircraft headings.

a. Tune and identify the station.

b. From the RMI, determine the number of degrees the bearing pointer is deflected to the right or to the left of the nose of the aircraft.

c. If the bearing is to the right of the nose, add the number of degrees determined in "b" above to the aircraft heading to determine the magnetic course to the station. If the bearing is to the left of the nose, subtract the number of degrees determined in "b" above from the aircraft heading to determine the magnetic course to the station.

15-14. HOMING TO A STATION (FIXED CARD)

Homing when using relative bearings is done in the same manner as described in paragraph 15-4. Turn the aircraft until the bearing pointer is alined with the index at the top of the RMI. Fly to the station by turning the aircraft as necessary to keep the bearing pointer on the nose of the aircraft.

15-15. STATION PASSAGE (FIXED CARD)

Station passage is indicated by a movement of the bearing pointer from its position at the index at the top of the RMI (if homing) or from its position at or near that index (if maintaining a course) to the reciprocal of that position.

TURN PAGE FOR "MAINTAINING A COURSE TO A STATION (FIXED CARD)"

15-16. MAINTAINING A [illegible] STATION [illegible]

Figure 15-7 depicts the procedure for maintaining the course to a station using relative bearings.

a. *Point A.* The aircraft is inbound to the station on a course of 350°, the heading is 350°, and the bearing pointer is indicating a 0° relative bearing.

b. *Point B.* Wind from the left has caused the aircraft to drift off course to the right. The bearing pointer indicates a 5-degree bearing to the left of the nose. The course is now 5° to the left.

c. *Point C.* To return to the course, 20° of left correction must be applied. The new heading is 330°. The bearing pointer indicates a bearing of 015° to the right of the nose of the aircraft.

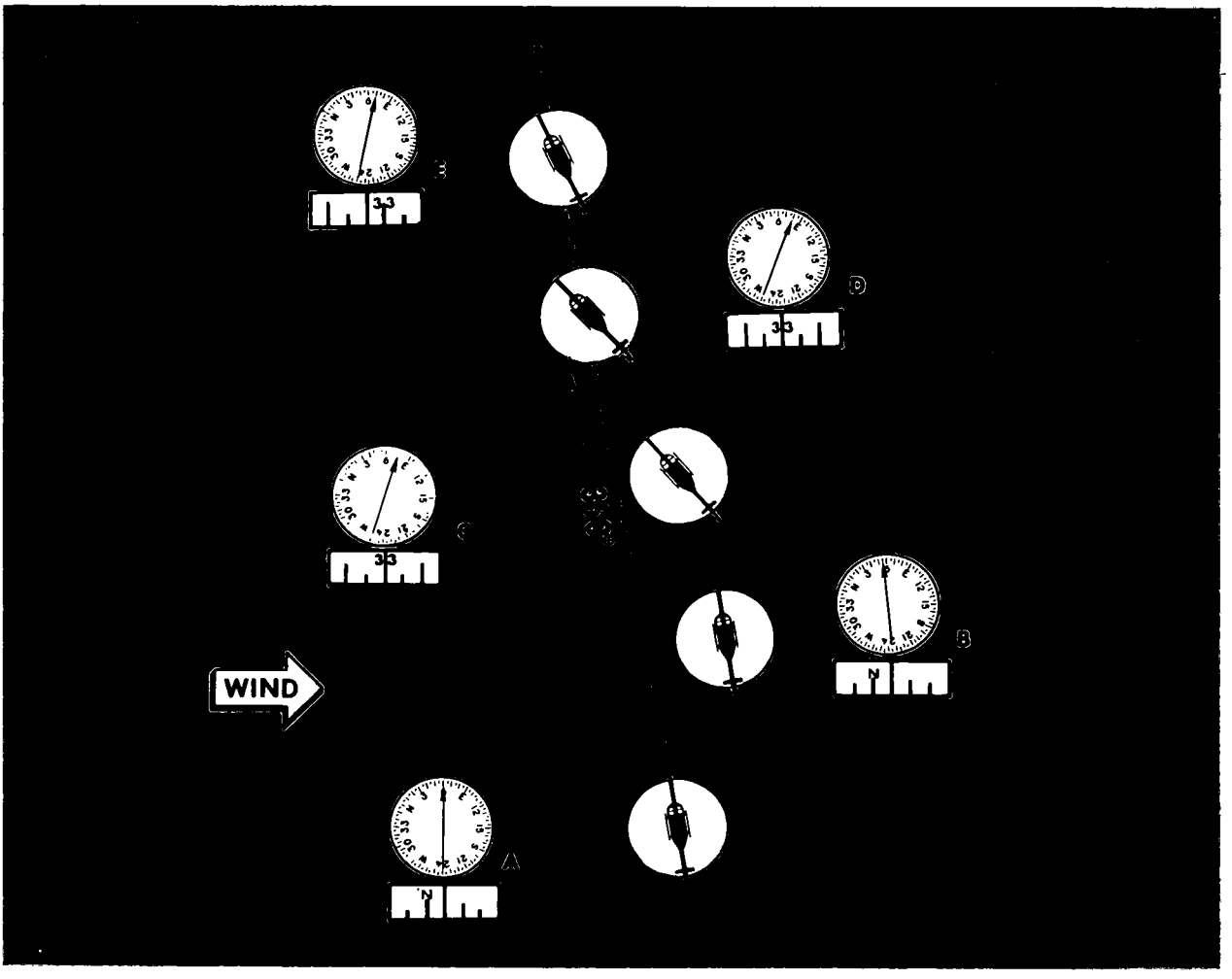


Figure 15-7. Maintaining a course to a station (fixed card).

d. *Point D.* The aircraft has returned to the course when the bearing pointer indicates a bearing of 20° to the right of the nose.

e. *Point E.* The aircraft is turned right to a heading of 340° (drift correction of 10° has been applied). (The bearing pointer indicates 10° has been applied.) The bearing pointer indicates 10° to the right of the nose. If the bearing pointer remains in this position, the drift correction is sufficient and the aircraft will remain on course. If not, further corrections to course will have to be made and different drift corrections must be applied until the course is maintained.

15-17. MAINTAINING A COURSE FROM A STATION (FIXED CARD)

Procedures for maintaining a course outbound are illustrated in figure 15-8.

a. *Point A.* The aircraft is outbound from the station on a course of 350°, the aircraft heading is 350°, and the bearing pointer is indicating a relative bearing of 180° from the nose of the aircraft (on the lower heading index of the RMI, considered as the tail of the aircraft).

b. *Point B.* Wind from the left of the course has caused the aircraft to drift to the right of the course. The bearing pointer indicates a position 5° to the left of the tail or lower index on the RMI.

c. *Point C.* A 20-degree heading change to the left is applied. The heading is 330°. The bearing pointer indicates a bearing of 25° to the left of the tail.

FM 1-5

d. *Point D.* The aircraft has returned to the course when the bearing pointer indicates a bearing of 20° to the left of the tail.

e. *Point E.* The aircraft is turned to a heading of 340° (drift correction of 10° has been applied). The bearing pointer indicates a bearing of 10° to the left of the tail. If this drift correction is sufficient, the bearing pointer will remain in this position and the aircraft will remain on course. If not, further corrections to course will have to be made and different drift corrections will have to be applied until the course is maintained.

Note. **Maintaining a course from a station can also be accomplished using the tail of the bearing pointer; however, the tail of the bearing pointer is nondirectional and corrections must be made in the opposite direction to the tail of the bearing pointer.**

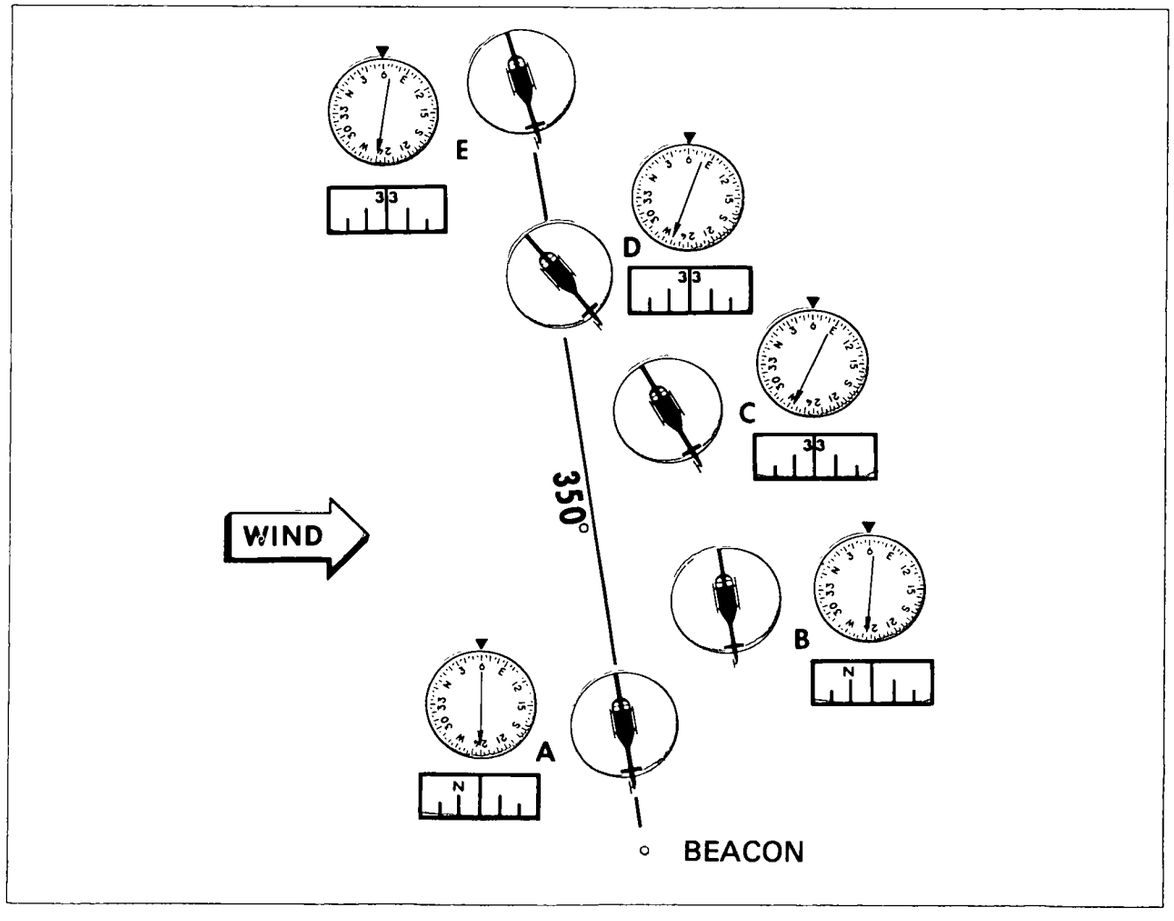


Figure 15-8. Maintaining a course from a station (fixed card).

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15-18. POSITION FIXING (FIXED CARD)

The procedures for determining a fix are illustrated in figure 15-9. The aircraft is maintaining a course of 090°. The ADF receiver is tuned to the beacon. A fix must be identified where the 120° course to the beacon crosses the 090° course. The aircraft will be at this position when the bearing pointer indicates 30° to the right of the nose. (120° - 90° = 30° difference between the two courses.) When drift correction is required to maintain a course, the heading of the aircraft will always be used to determine the relative bearing to a fix. *Example:* The heading of the aircraft is 080° (10° drift correction to the left) and is maintaining a 090° course. When the fix is reached, the bearing pointer will indicate a position of 40° to the right of the nose (120° - 80° = 40°). In the same example, a 10-degree right drift correction will result in the bearing pointer indicating 20° right of the nose at the fix (120° - 100° = 20°).

15-19. COURSE INTERCEPTION INBOUND (FIXED CARD)

The procedures for course interception to a station are illustrated in figure 15-10.

a. *Point A.* At point A, the aircraft is inbound to a beacon on a course of 050°. The aircraft heading is 050° and the bearing pointer is indicating a zero-degree relative bearing. The requirement exists to intercept a course of 80° to the beacon. The 80° course can be visualized as being to the left or can be determined by turning the aircraft parallel to a heading of 080° and

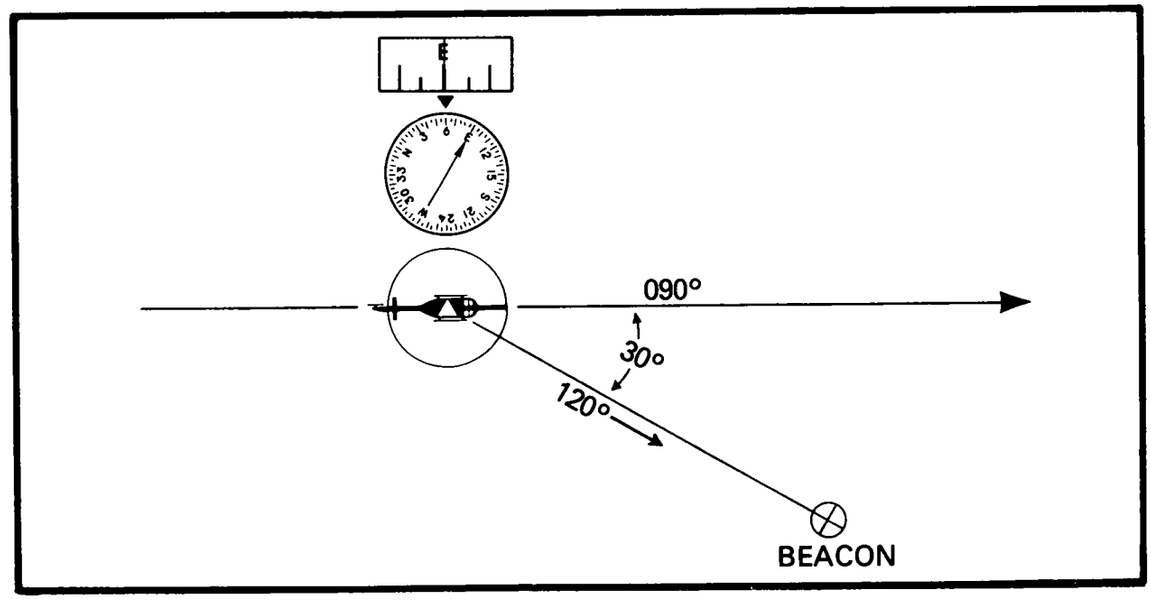

Figure 15-9. Position fixing (fixed card).

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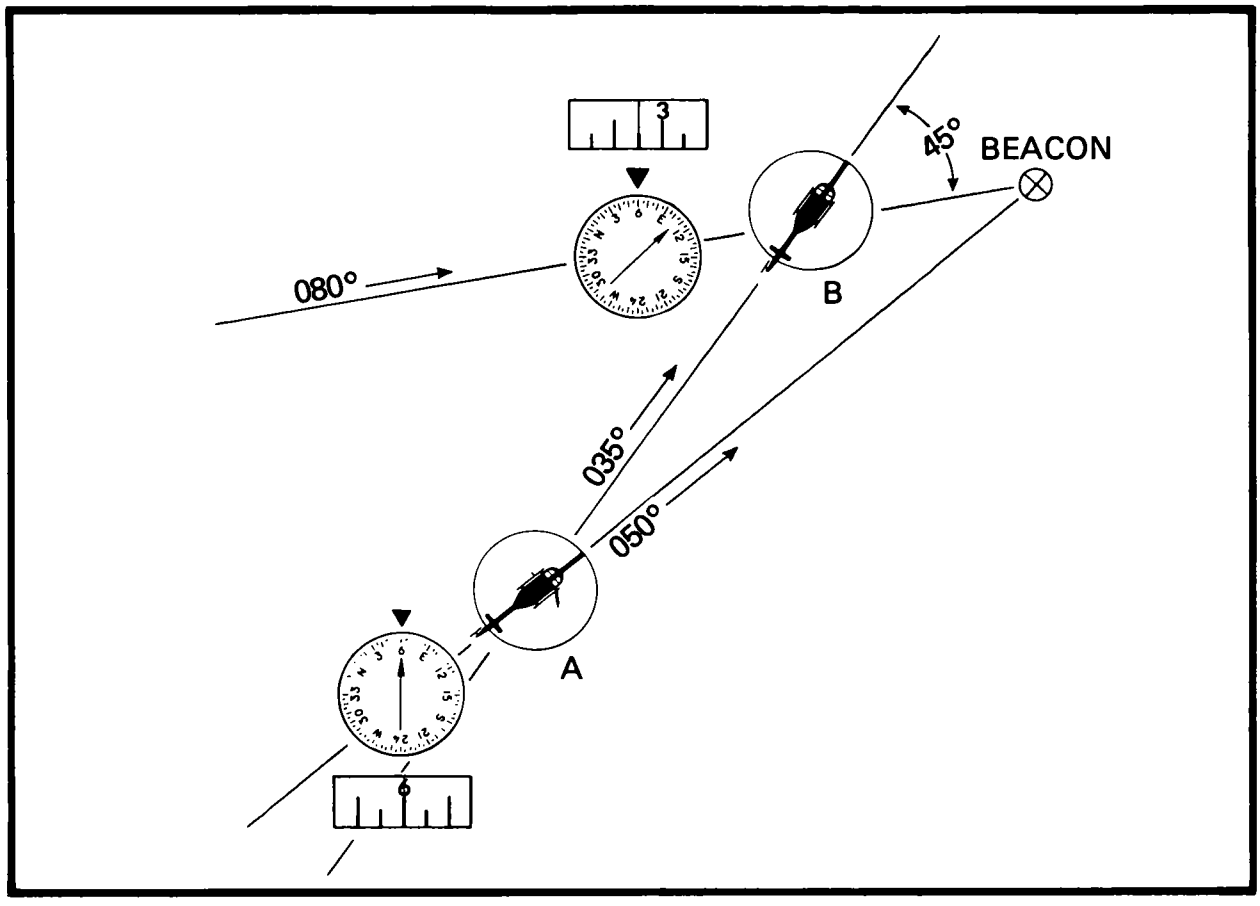

Figure 15-10. Course interception inbound (fixed card).

noting that the bearing pointer is indicating a bearing to the left of the nose. Since there is a 30-degree difference between the two courses, a 45-degree intercept angle is applied. The aircraft is turned left to a heading of 035°.

b. *Point B.* At point B, the aircraft has intercepted the 080° course. The bearing pointer indicates a bearing of 045° to the right of the nose of the aircraft. The turn to course must be started before the bearing pointer reaches the 045° bearing. (See paragraph 15-9 for a discussion of how to plan a turn to intercept a course.)

15-20. COURSE INTERCEPTION OUTBOUND (FIXED CARD)

The interception of a course from a station is illustrated in figure 15-11.

TURN PAGE FOR FIGURE 15-11.

a. *Point A.* At point A, the aircraft is maintaining a course of 270° from the station. The aircraft heading is 270° and the bearing pointer is indicating a relative bearing of 180°. The requirement exists to intercept a course of 300° from the station. The parallel or visual method can be used to determine the direction of the 300° course from the 270° course. On a heading of 300°, the bearing pointer will indicate to the right of 240° or tail of the aircraft. The 300° course is to the right of the present position of the aircraft. To intercept the desired course of 300°, the aircraft must be turned to the right to a heading of 345° (300° course + 45° intercept angle).

b. *Point B.* At point B, the aircraft has intercepted the 300° course. The bearing pointer indicates a bearing of 045° to the right of the 180° index or tail of the aircraft. The turn to course must be started prior to the bearing pointer reaching the 045° bearing. (See paragraph 15-9 for a discussion of how to plan to intercept a course.)

15-11. DETERMINATION OF TIME AND DISTANCE FROM A STATION (FIXED CARD)

The procedures for determining the time and distance from a station using a fixed compass card are the same as those set forth in paragraph 15-11.

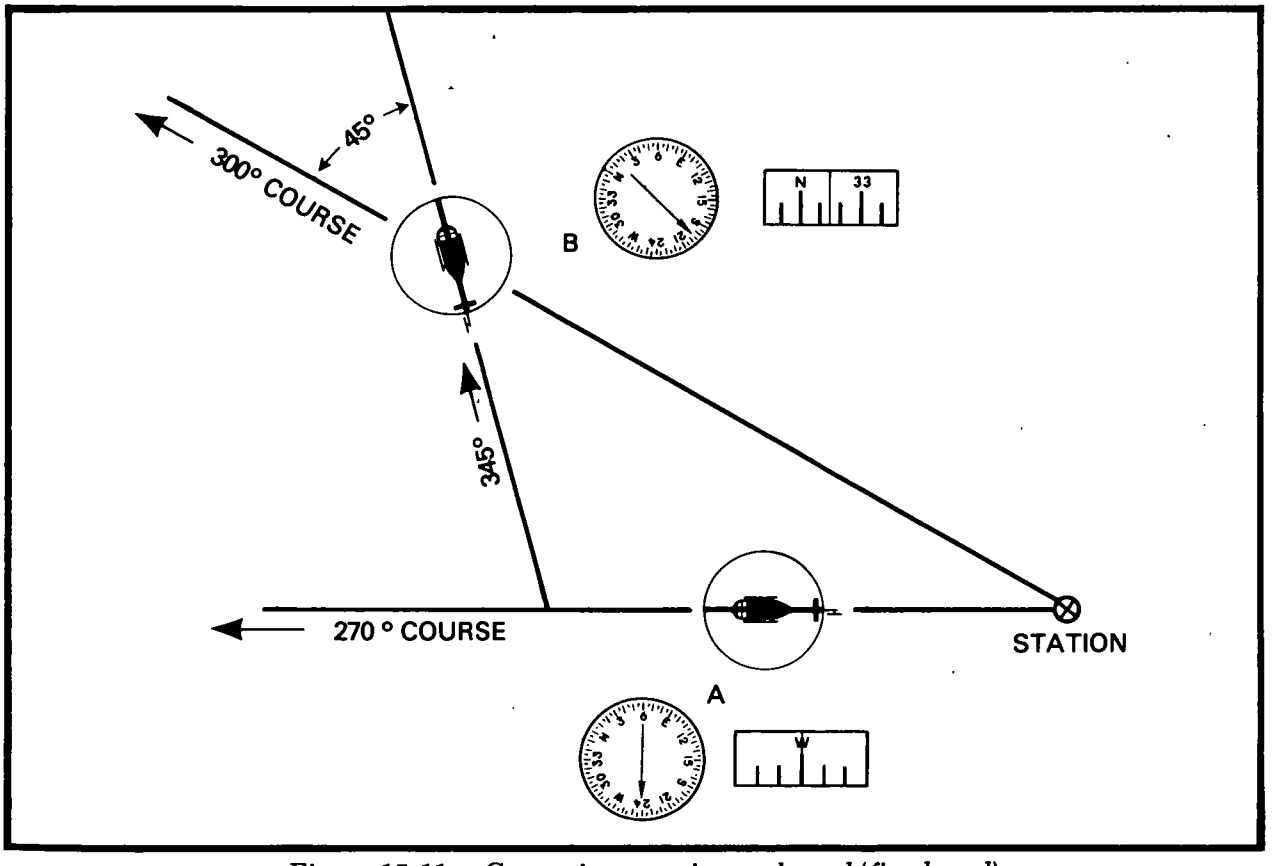

Figure 15-11. Course interception outbound (fixed card).

Section IV. MANUAL (LOOP) OPERATION OF THE ARN-59

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a. *Selection of Mode of Operation.* The radio compass may be operated manually for navigational use with the selector switch in the LOOP position. Manual operation may be necessary when the signal or indicator readings received in the COMP position are unreliable. Navigational procedures are the same in the LOOP position as when using the COMP position; however, the azimuth indicator is positioned manually by the loop drive switch to locate the null by sound. If the switch is moved to the right, the indicator arrow moves to the right (clockwise); if the switch is moved to the left, the indicator moves to the left (counterclockwise). An aural null (minimum reception) results when the plane of the loop antenna is perpendicular to a line from the beacon.

b. *Beat Frequency Oscillator (BFO).* Certain types of radio beacons transmit an interrupted but unmodulated radio carrier wave which is inaudible unless the BFO switch is turned on. The beat frequency oscillator (on some ADF receivers the "BFO" switch is labeled "CW") converts the inaudible carrier wave into an audible sound. Other radio beacons transmit a continuous repetition of the identifier code or transmit a tone interrupted at intervals by the identifier code. These beacons are difficult to identify in manual loop operation unless the BFO is turned to the ON position. The BFO will combine with the incoming signal and produce a continuous audible tone. This will aid in determining the null by insuring a better signal. Therefore, the BFO switch must be on during all manual loop operations.

[redacted] ORIENTATION

Orientation procedures used in determining the direction to the radio transmitter are explain below.

a. Tune and identify the radio beacon in the ANT position. If it is difficult to identify the beacon, switch the LOOP position and listen for the identifier. If it is not heard, rotate the loop with the loop drive switch until the identifier is heard. (The loop may have been in the null position when the receiver was switched to LOOP.) The reception of the station being tuned may be improved by turning on the BFO switch. Best reception is attained by moving the tuning dial slowly back and forth over the station frequency until the position is located where the highest pitched tone is heard. The monotone or aural signal caused by the BFO will be heard on either side of the highest tone.

b. Move the selector switch to LOOP if the selector switch is not already positioned in this mode.

c. Move the loop drive switch and listen to the signal. At some point the

signal will fade; this is the null position. As the aviator rotates the azimuth indicator, the signal will build on each side of the null position. Ideally, the null should be no more than 5° wide on the face of the azimuth indicator. *For example,* if the signal begins to fade when the indicator reaches 120° and immediately builds up again at 125°, the null is reasonably narrow. After the null is located, the azimuth indicator points toward the beacon but the indication is ambiguous; i.e., the correct relative bearing may be at either end of the indicator. If the null is more than 5° wide, increase the volume with the volume control until the null is 5° wide. If the null is too narrow or cannot be definitely located, decrease the volume.

d. To resolve the ambiguity, rotate the loop manually until the bearing pointer indicates 090° or 270° from the nose of the aircraft. Turn the aircraft right or left until the signal again fades to a null. The beacon is then either to the left or to the right of the aircraft. Maintain a constant heading while using the loop drive switch to maintain the null position. If the loop (bearing pointer) is rotated to the right to maintain the null, the beacon is to the right (clockwise) of the aircraft; if rotated to the left to maintain the null, the beacon is to the left of the aircraft. Procedures for resolving ambiguity are illustrated in figure 15-12.

(1) *Point A.* At point A, the aural null is received on a compass heading of 270°, with the bearing pointer in the 0° to 180° position. The beacon is either directly ahead of or behind the aircraft.

(2) *Point B.* At point B, the bearing pointer is rotated to the 090°/270° (wingtip) position, which causes the signal to rebuild.

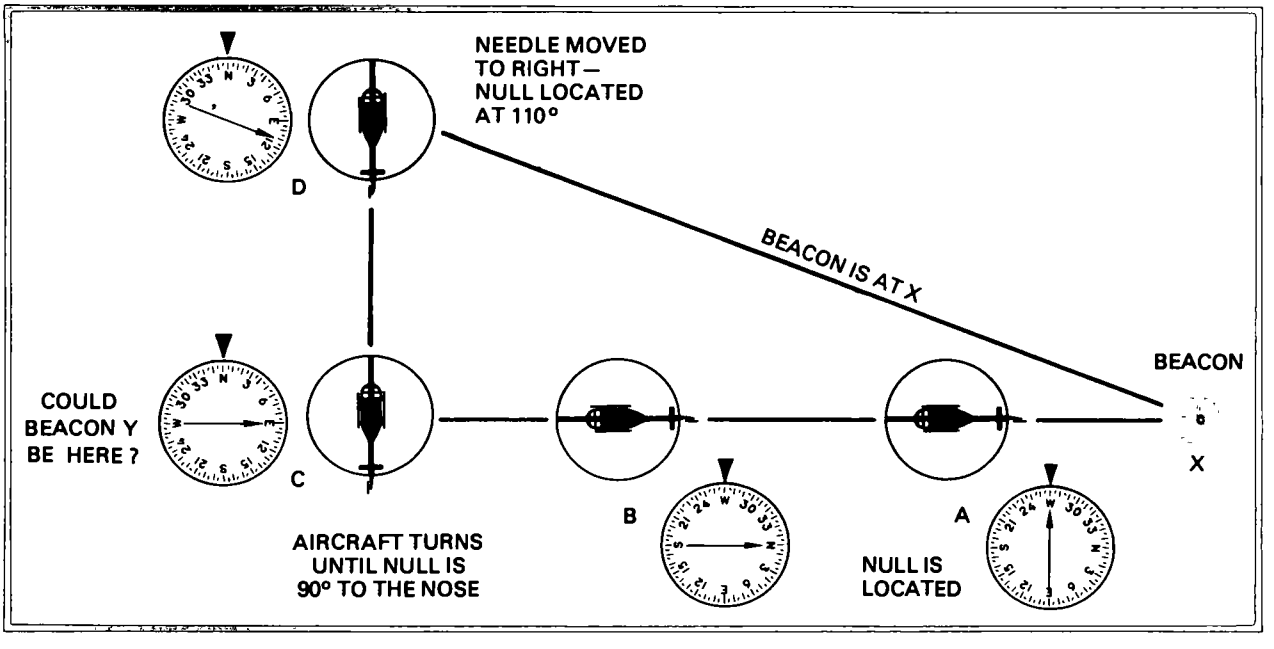


Figure 15-12. Resolving ambiguity (loop).

(3) *Point C.* At point C, the aircraft is turned until the null reappears at the wingtip position (heading 0°), indicating the beacon is either to the left or right of the aircraft. The aviator flies this heading for a short time and the signal rebuilds. This indicates that the aircraft has flown out of the wingtip null.

(4) *Point D.* The null is relocated at point D by rotating the bearing pointer clockwise to 110°. Therefore, the beacon is at point X, 110° right of the aircraft heading of 0°.

15-24. HOMING

a. Homing to a beacon with the receiver operating in the LOOP position is accomplished by first locating the beacon (para 15-23) and then turning the aircraft until the null is on the nose position. If the aircraft drifts out of the null position, the direction of drift is determined by rotating the bearing pointer left or right to relocate the null (para 15-23d). The aircraft is turned until the null is again on the nose position. This procedure is repeated until in the immediate vicinity of the beacon.

b. To determine arrival over the beacon—

(1) Estimate the time of arrival accurately.

(2) Prior to arrival, set the bearing pointer on the wingtip position (090° to 270°) with the loop drive switch to receive a strong signal.

(3) As the aircraft flies over the beacon (or abeam the beacon), a sharp null of short duration will be detected.

15-25. TRACK

Aural null tracking procedures are identical to those used for ADF tracking except that the loop must be manually rotated to determine the null position and relative bearing. In tracking toward or away from a beacon (null at 0° or 180°), drift is indicated by movement of the null to the left or right of the nose or tail position. *For example*, if the aircraft drifts off course to the left, a 20° heading correction may be made to reintercept the null. Procedures are as follows:

a. Using the heading indicator, turn 20° right to intercept the course. Set the indicator (loop) to 20° left of the nose.

b. Continue on the same heading until the null reappears at this new setting (20° left of nose). Aircraft is back on desired course.

c. Turn back toward original heading by 10° and relocate the null indicator 10° left of nose.

d. If correction of 10° is excessive or inadequate, make additional corrections of 5°.

To compute the time and distance to an L/MF station, tune and identify the station and place the bearing pointer on the 90° or 270° position with the loop switch. Turn the aircraft until the null is located. Note the time and maintain this heading. Move the loop, keeping it in the null position as the aircraft continues to advance. When the bearing pointer has been moved 10°, note the elapsed time and apply the formulas from paragraph 15-11.

CHAPTER 16

THE DOPPLER NAVIGATION SET AND COMMAND INSTRUMENT SYSTEM

Section I. DOPPLER SYSTEM DESCRIPTION

16-1. GENERAL

This chapter provides a reference for the use of the doppler navigation set (DNS) AN/ASN-128. The doppler navigation set AN/ASN-128 used in some Army aircraft is composed of the computer-display unit (CDU), signal data converter, and the receiver-transmitter-antenna. The DNS, in conjunction with the aircraft's heading and vertical references, provides aircraft velocity, position, and steering from ground level to above 10,000 feet. See figures 16-1 and 16-2.

16-2. DOPPLER NAVIGATION SET AN/ASN-128

a. *General.* The AN/ASN-128 is a completely self-contained navigation system and does not require any ground-based aids. The system provides worldwide navigation, with position readout available in both universal transverse mercator (grid) (UTM) and latitude and longitude (lat/long). Navigation and steering is done using lat/long coordinates, and a bilateral UTM-lat/long conversion routine is provided for UTM operation.

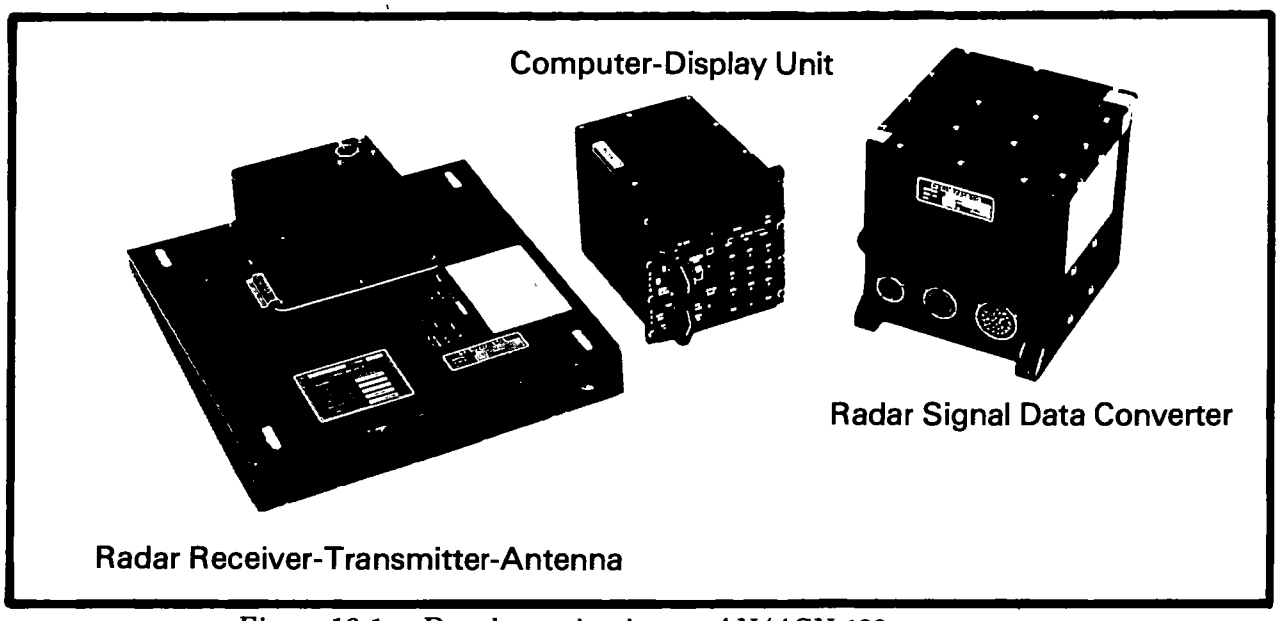


Figure 16-1. Doppler navigation set AN/ASN-128 components.

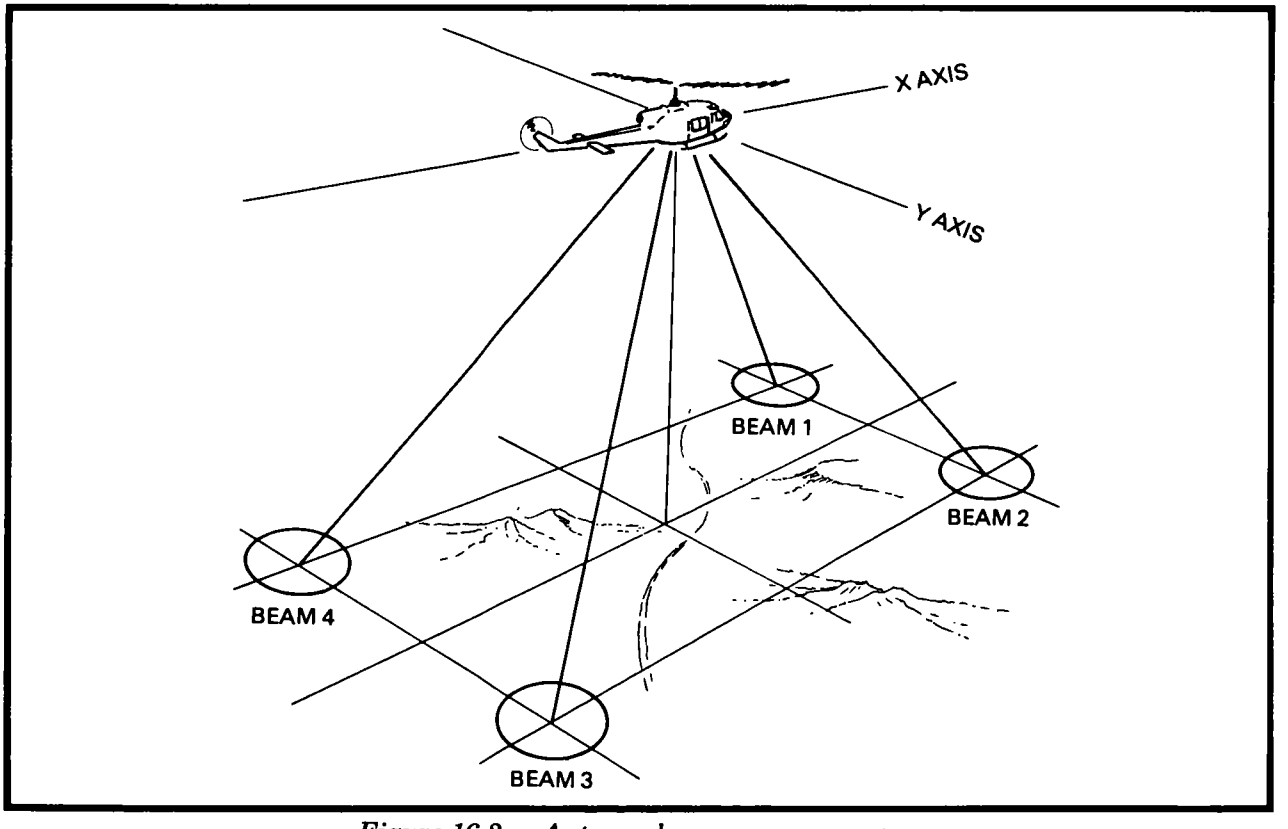


Figure 16-2. Antenna beam arrangement.

b. *System Operation.*

(1) The navigation set requires the following aircraft inputs:

(a) 28 volts direct current (DC) primary power from the aircraft power source.

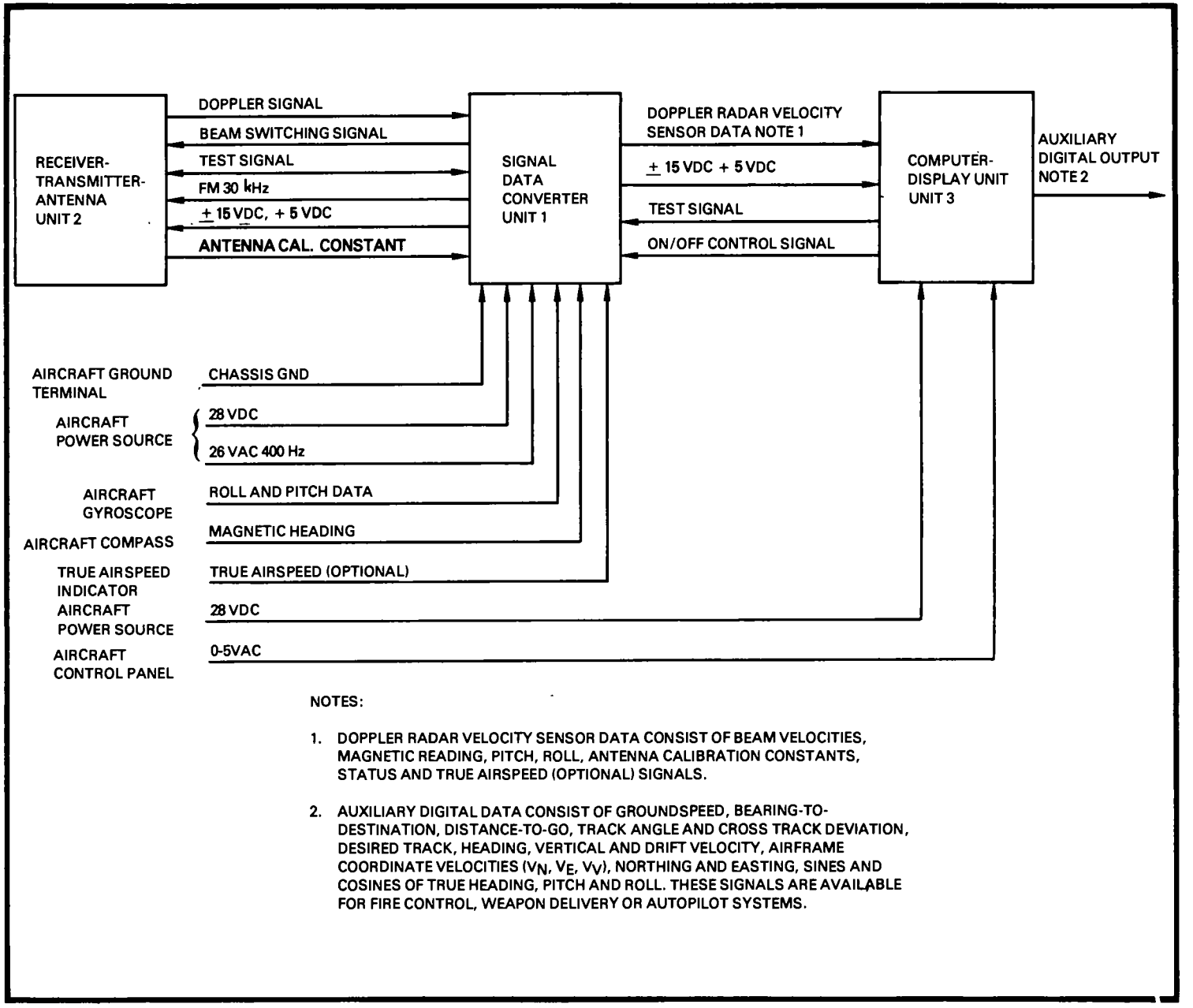
(b) 26 volts alternating current (AC) 400 hertz (Hz) synchro reference signal.

(c) 5 volts AC 400 Hz computer-display unit panel lighting.

(d) Roll, pitch, and magnetic heading in standard three-wire synchro form.

(2) The navigation set is energized when the computer-display unit mode switch is rotated from the OFF position to any of the other positions. This causes an on/off control discrete signal to be sent from the computer-display unit to the signal data converter (fig 16-2). The signal data converter then supplies $\pm$ 15 and +5 volts DC power to the receiver-transmitter-antenna and computer-display unit. It also supplies a beam switching signal and a 30-kilohertz (kHz) frequency modulating signal to the receiver-transmitter-antenna. The receiver-transmitter-antenna generates a transmitter carrier frequency at 13.325 gigahertz (GHz) and frequency modulates this radio frequency (RF) carrier with the 30 kHz sinusoidal signal. The resulting frequency modulated/continuous wave (FM-CW) signal is applied to the antenna. The antenna simultaneously radiates and receives four non-coplanar switched beam signals in a sequential fashion as shown in figure 16-3. Within 5 seconds after turn-on, the doppler radar will have searched for and locked on to the received doppler shifted signal. The doppler radar velocity sensor (DRVS), comprised of the signal data converter and the receiver-transmitter-antenna, processes the beam velocity signals and transmits the doppler information to the computer-display unit together with pitch, roll, and magnetic heading data; antenna calibration constants; and airspeed. The computer-display unit accepts these inputs and computes the three orthogonal components of aircraft velocity in ground coordinates, and combines aircraft velocity and heading data to compute changes in aircraft position.

(3) During system operation, the navigation set is monitored by test signals to detect failures. The computer-display unit, using its own computer as built in test equipment (BITE) processes these test signals and displays coded data which indicates the defective unit or circuit card of the navigation set.



NOTES:

1. DOPPLER RADAR VELOCITY SENSOR DATA CONSIST OF BEAM VELOCITIES, MAGNETIC READING, PITCH, ROLL, ANTENNA CALIBRATION CONSTANTS, STATUS AND TRUE AIRSPEED (OPTIONAL) SIGNALS.

2. AUXILIARY DIGITAL DATA CONSIST OF GROUNDSPEED, BEARING-TO-DESTINATION, DISTANCE-TO-GO, TRACK ANGLE AND CROSS TRACK DEVIATION, DESIRED TRACK, HEADING, VERTICAL AND DRIFT VELOCITY, AIRFRAME COORDINATE VELOCITIES (V_N, V_E, V_V), NORTHING AND EASTING, SINES AND COSINES OF TRUE HEADING, PITCH AND ROLL. THESE SIGNALS ARE AVAILABLE FOR FIRE CONTROL, WEAPON DELIVERY OR AUTOPILOT SYSTEMS.

Figure 16-3. Navigation set system block diagram.

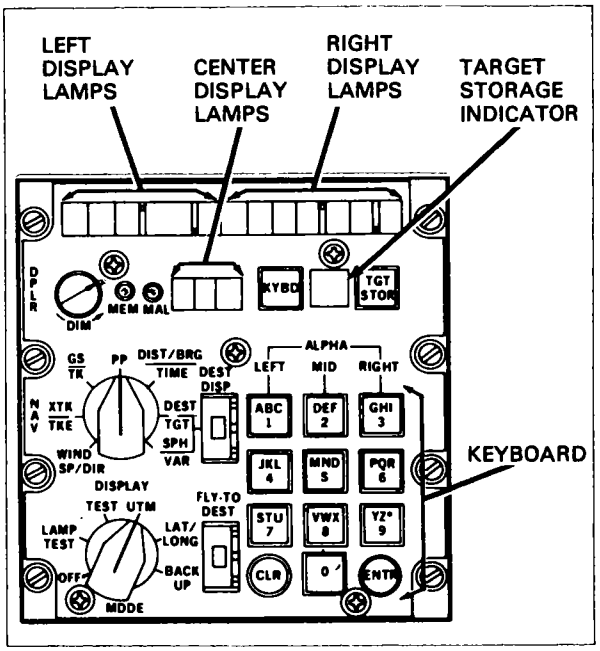


Figure 16-4. Doppler navigation set AN/ASN-128.

16-3. CONTROLS, DISPLAYS, AND FUNCTION

The controls and displays for the doppler are on the front panel of the computer display unit (fig 16-4). The function of each control is as follows:

CONTROL/ INDICATOR	FUNCTION
MODE Selector	Selects doppler navigation mode of operation.
OFF	Turns navigation set off.
LAMP TEST	Checks operation of all lamps.
TEST	Initiates built-in test exercise for navigation set.
UTM	Selects universal transverse mercator display/entry.
LAT/LONG	Select latitude/longitude display/entry.
BACKUP	Places navigation set in true airspeed (TAS) plus remembered wind mode of operation, or estimated velocity of operation.
DISPLAY selector	Selects navigation data for display.
WIND SP/DIR	Used only with BACKUP mode.
(Left Display)	Windspeed (kilometer(s) (km) per hour).
(Right Display)	Direction (degrees).
XTK/TKE	
(Left Display)	Distance crosstrack error (XTK) in km and tenths of a km.
(Right Display)	Track angle error (TKE) in degrees.
GS/TK	
(Left Display)	Groundspeed (GS) in km/hr.
(Right Display)	Track angle in degrees.
PP with switch set to UTM	
(Center Display)	Present position UTM zone.
(Left Display)	Present position UTM square designator and easting in km to nearest 10 meters.
(Right Display)	Present position UTM northing in km to nearest 10 meters.

CONTROL/ INDICATOR	FUNCTION
PP with MODE switch set to LAT/LONG	
(Left Display)	Present position latitude in degrees, minutes, and tenths of minutes.
(Right Display)	Present position longitude in degrees, minutes, and tenths of minutes.
DEST/BRG/TIME	
(Center Display)	Time to fly to destination in minutes.
(Left Display)	Distance to fly to destination in km and tenths of a km.
(Right Display)	Bearing to fly to destination in degrees.
DEST/TGT	
(Center Display)	UTM zone of destination set on DEST DISP thumbwheel.
(Left Display)	UTM square designator, and easting or latitude of destination set on DEST DISP thumbwheel.
(Right Display)	UTM northing or longitude of destination set on DEST DISP thumbwheel.
SPH/VAR	
(Left Display)	Spheroid code of destination set on DEST DISP thumbwheel.
(Right Display)	Magnetic variation (in degrees and tenths of degrees) of destination set on DEST DISP thumbwheel.
MAL Indicator Lamp	Lights when navigation set malfunctions. In case of an intermittent malfunction, system may operate correctly, but must by cycled to OFF and then ON to put MAL light off.

CONTROL/ INDICATOR	FUNCTION
MEM Indicator Lamp	Lights when radar portion of navigation set is in a nontrack condition.
DIM Control	Controls light intensity of display characters.
Left, Right, and Center Display Lamps	Alphanumeric characters that display data, as determined by setting of DISPLAY switch.
Target Storage Indicator	Displays destination number (memory location) in which present position will be stored when TGT STOR pushbutton is pressed.
TGT STOR Pushbutton	Stores present position data when pressed.
KYBD Pushbutton	Used in conjunction with keyboard to allow data entry. KYBD pushbutton is always lighted when system is on.
DEST DISP Thumbwheel Switch	Destination display thumbwheel switch is used along with DEST/TGT and SPH/VAR position of DISPLAY switch to select destination whose coordinates or magnetic variation are desired. Destinations are 0 through 9, P (present position) and H (home).
Keyboard	Used to enter data into system. Keys set up data on display. ENTR key enters display data into system. CLR key, when pressed once, clears last characters entered on display. When pressed twice, this key clears display under control.
FLY-TO-DEST Thumbwheel Switch	Fly-to-destination thumbwheel switch selects destination to which steering information is desired. Destinations are 0 through 9. P (present position) and H (home).

16-4. MODES OF OPERATION

The three basic modes of operation are TEST, NAVIGATE, and BACKUP.

a. *Test Mode.* The TEST function contains two modes: LAMP TEST mode, in which all display segments are lit; and TEST mode, in which system operation is verified. In the LAMP TEST mode, system operation is identical to that of the navigate mode except that all lamp segments and the MEM and MAL indicator lamps are lighted to verify their operation (fig 16-5). In TEST mode, the system antenna no longer transmits or receives electromagnetic energy; instead, self-generated test signals are inserted into the electronics to verify operation. System operation automatically reverts into the BACKUP mode during TEST mode.

b. *Navigate Mode.* In the NAVIGATE mode (UTM or LAT/LONG position of the MODE selector), power is applied to all system components, and all required outputs and functions are provided. Changes in present position are computed and added to initial position to determine the instantaneous latitude/longitude of the helicopter. Destination and present position coordinates can be entered and displayed in UTM and latitude/longitude. At the same time, distance, bearing, and time-to-go to any one of ten present destinations are computed and displayed as selected by the FLY-TO-DEST thumbwheel.

c. *Backup Mode.* In this mode, remembered DRVS velocity data are used to complete position. This remembered velocity data can be manually updated through use of the keyboard and CDU DISPLAY switch in the GS/TK position. When GS/TK values are inserted under these conditions, navigation continues using only these values.

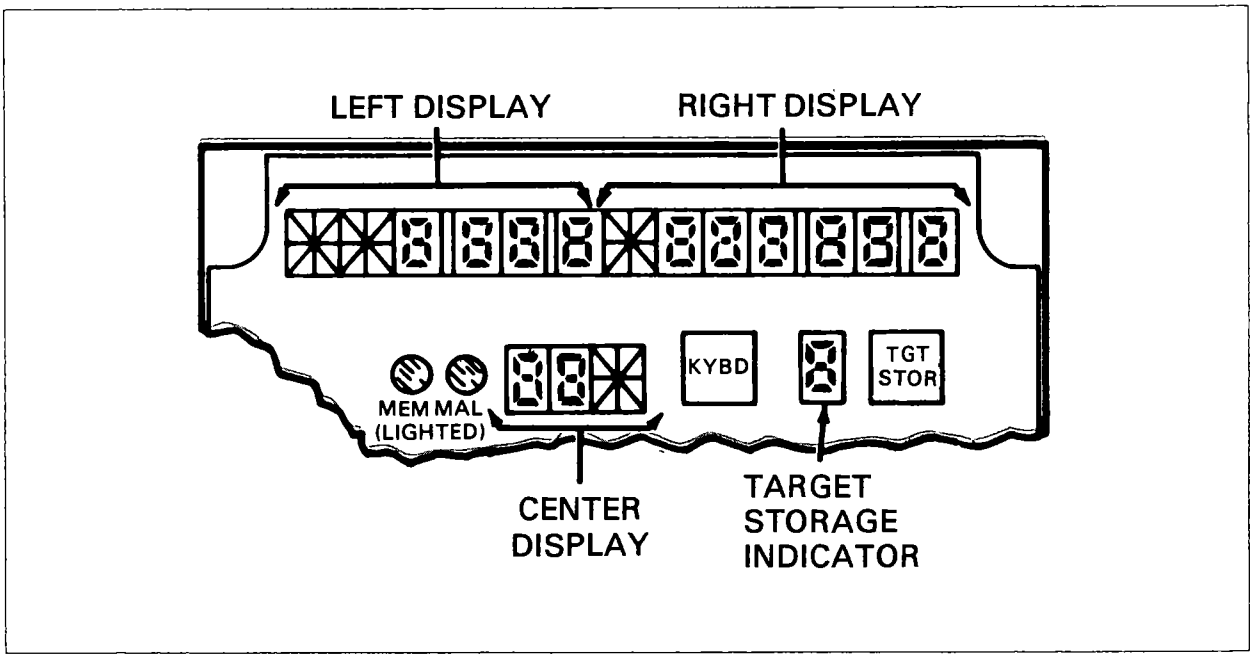


Figure 16-5. Doppler test mode display.

Section II. DOPPLER SYSTEM OPERATION

[redacted]

In all data displays except UTM coordinates, the two fields are the left and right display windows. In UTM coordinates displays, the first field of control is the center window and the second field is the combination of the left and right displays. When pressing the KYBD pushbutton, one or the other of the fields described above is under control. If it is not desired to change the display in the panel section under control, the pilot can advance to the next field of the display panel by pressing the KYBD pushbutton again.

[redacted]

To enter a numeric, press the corresponding key. To enter a letter, first press the appropriate row key (LEFT 1, 4, or 7; MID 2, 5, or 8; RIGHT 3, 6, or 9 key for left, middle or right, respectively), and then press the key corresponding to the letter desired.

Example: To enter an A, first press the 1, 4, or 7 key, then the A key. The computer program is designed to reject unacceptable data (for example, a UTM area of WI does not exist, and will be rejected). If the operator attempts to insert unacceptable data, the display will be blank after ENTR is pressed.

16-7. STARTING PROCEDURE

a. MODE selector—LAMP TEST. All lights should be lit.

(1) Left, right, center, and target storage indicator—lit. All other lights should be on.

(2) Turn DIM control fully clockwise, then fully counterclockwise, and return to full clockwise; all segments of the display should alternately glow brightly, go off, and then glow brightly.

b. MODE selector—TEST. After about 15 seconds left display should display GO. Ignore the random display of alpha and numeric characters which occurs during the first 15 seconds. Also ignore test velocity and angle data displayed after the display has frozen. After about 15 seconds, one of the following five displays will be observed in the first two character positions in the left display:

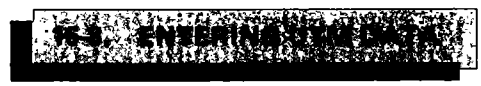
Note. **If the MAL lamp lights during any mode of operation except LAMP TEST, the computer-display unit MODE switch should be turned first to OFF, and then to TEST, to verify the failure. If the MAL lamp remains on after recycling to TEST, notify organizational maintenance personnel of the navigation set malfunction.**

DISPLAY		REMARKS
LEFT	RIGHT	
GO	No display. Display blanks (normal).	If right display is blank, system is operating satisfactorily.
GO	P	If right display is P, then pitch or roll data is missing, or pitch exceeds 90°. In this case, pitch and roll in the computer are both set to zero and navigation continues in a degraded operation. Problem may be in the vertical gyroscope or helicopter cabling.

Note. **If the TEST mode display is BU, MN or NG, the MODE switch should be recycled through OFF to verify that the failure is not a momentary one. If the TEST mode display is BU or MN, the data entry may be made in the UTM or LAT/LONG mode, but any navigation must be carried on with the system in the BACKUP mode.**

BU	C, R, S, or H followed by a numeric code.	A failure has occurred and the system has automatically switched to a BACKUP mode of operation as follows: 1. The operator has the option of turning the MODE switch to BACKUP and entering the best estimate of groundspeed and track angle. 2. The operator has the option of turning the MODE switch to BACKUP and entering his best estimate of windspeed and direction and entering his best estimate of groundspeed and track angle. The operator should update present position as soon as possible, because it is possible that significant navigation errors may have accumulated.
MN	C, R, S, or H followed by a numeric code.	A failure has occurred and the BACKUP mode, used for manual navigation (MN), is the only means of valid navigation. The operator may use the computer as a dead reckoning device by entering groundspeed and track data. The operator should update present position as soon as possible, because it is possible significant navigation errors may have accumulated.
NG	C, R, S, or H followed by a numeric code.	A failure has occurred in the system and the operator should not use the system.
EN		The 9-volt battery has failed. All stored data must be reentered.

Note. **If the TEST mode display is BU, MN or NG, the MODE switch should be recycled through OFF to verify that the failure is not a momentary one. If the TEST mode display is BU or MN, the data entry may be made in the UTM or LAT/LONG mode, but any navigation must be carried on with the system in the BACKUP mode.**



This initial data is inserted before navigating with the doppler:

a. Spheroid of operation, when using UTM coordinates.

b. UTM coordinates of present position—zone, area, easting (four significant digits) and northing (four significant digits).

c. Variation of present position to the nearest one-tenth of a degree.

d. Coordinates of desired destination—0 through 5 and H; (6 through 9 are normally used for target store locations, but may also be used for destinations). It is not necessary to enter all destinations in the same coordinate system.

Note. **It is not necessary to enter destinations unless steering information is required, unless it is desired to update present position by overflying a destination or unless a present position variation computation is desired (para 16-4c). If a present position variation running update is desired, destination variation must be entered. The operator may enter one or more destination variations to effect the variations update; it is not necessary for all destinations to have associated variations entered.**

e. Variations of destinations to be to nearest one-tenth of a degree.

a. MODE selector—UTM, LAT/-LONG or BACKUP.

b. DISPLAY selector—SPH/VAR.

c. DEST DISP thumbwheel—P, numeral, or H as desired.

d. KYBD pushbutton—Press. Observe display freezes.

e. Spheroid data—Entry. (Example: INO). Press keys 3 (left window blanks), 3, 5, 5, and 0. Right display should indicate INO.

f. KYBD pushbutton—press if no spheroid data is to be entered.

g. KYBD pushbutton—press if variation data is to be entered.

h. Variation data—enter. (Example: E001.2, press keyboard keys 2 (right window blanks), 2, 0, 0, 1, and 2. Press ENTR key; display should indicate E001.2.)

i. ENTR pushbutton—press if no variation data is to be entered.

16-10. ENTERING PRESENT POSITION OR DESTINATION IN UTM

a. MODE selector—UTM.

b. DISPLAY selector—DEST/TGT.

c. DEST DISP thumbwheel—P, numerical, or H as desired.

d. Present position or destination—Enter. (Example: Entry of zone 31T, area CF, easting 0958 and northing 3849; press KYBD pushbutton. Observe that display freezes; press keys 3 (display under control will clear except for entered 3), 1, 8, and 7. Press KYBD pushbutton and keys 3 (display under control will clear), 1, 3, 2, 0, 9, 5, 8, 3, 8, 4, and 9.)

e. ENTR pushbutton—press.

16-11. ENTERING PRESENT POSITION OR DESTINATION VARIATION IN LAT/LONG

The variation of a destination must be entered after the associated destination coordinates are entered (since each time a destination is entered, its associated variation is deleted). The order of entry for present position is irrelevant.

Note. **If operation is to occur in a region with relatively constant variation, the operator enters variation only for present position, and the computer will use this value throughout the flight.**

a. MODE selector—LAT/LONG.

b. DISPLAY selector—DEST/TGT.

c. DEST DISP thumbwheel—P, numerical or H as desired.

d. Present position or destination—enter. (Example: Entry of N41° 10.1 minutes and E035° 50.2 minutes. Press KYBD pushbutton. Observe that display freezes. Press keys 5 (left display will clear), 5, 4, 1, 1, 0, and 1. Press KYBD pushbutton and keys 2 (right display should clear), 2, 1, 3, 5, 0, and 2.)

e. ENTR pushbutton—press.

16-12. ENTERING GROUNDSPEED AND TRACK

a. MODE selector—BACKUP.

b. DISPLAY selector—GS/TK.

c. Windspeed and direction—enter. (Example: Enter 50 km/hr and 130°. Press KYBD pushbutton, press keys 0 (left display blanks except for 0 character entered), 5 and 0. Left display indicates

050. Press KYBD pushbutton, control shifts to right display. Press keys 1 (right display blanks except for 1 character entered), 3 and 0.

d. ENTR pushbutton—press.

16-3. INITIAL DATA ENTRY

Initial data entry variation coordinates are normally done prior to takeoff. To make the initial data entry, do the following:

a. Present position variation—enter (para 16-8).

b. DISPLAY selector—DEST/TGT.

c. DEST DISP thumbwheel—P. Do not press ENTR key now.

d. ENTR pushbutton—press as helicopter overflies initial fix position.

e. FLY-TO-DEST thumbwheel—desired destination location.

16-14. UPDATE OF PRESENT POSITION FROM STORED DESTINATION

The helicopter is flying to a destination set by the FLY-TO-DEST thumbwheel. When the helicopter is over the destination, the computer updates the present position when the KYBD pushbutton is pressed, by using stored destination coordinates for the destination number shown in FLY-TO-DEST window, and adding to them the distance traveled between the time the KYBD pushbutton was pressed and the ENTR key was pressed.

a. DISPLAY selector—DEST/BRG/TIME.

b. KYBD pushbutton—press. Display freezes.

Note. **If a present position update is not desired, as indicated by an appropriately small value of distance to go on overflying the destination, set the DISPLAY selector to some other position; this aborts the update mode.**

c. ENTR key—press.

16-15. UPDATE OF PRESENT POSITION FROM LANDMARK

There are two methods for updating present position from a landmark. Method 1 is useful if the landmark comes up unexpectedly and the operator needs time to determine the coordinates. Method 2 is used when a landmark update is anticipated.

a. *Method 1.*

(1) DISPLAY selector—PP.

(2) KYBD pushbutton—press as landmark is overflown. Present position display will freeze.

(3) Compare landmark coordinates with those on display.

(4) Landmark coordinates—enter if difference warrants an update.

(5) ENTR key—press.

(6) DISPLAY selector—set to some other position to abort update.

b. *Method 2.*

(1) DISPLAY selector—DEST/TGT.

(2) DEST DISP thumbwheel—P. Present position coordinates should be displayed.

(3) KYBD pushbutton—press.

(4) Landmark coordinates—manually enter via keyboard.

(5) ENTR key—press when overflying landmark.

(6) DISPLAY selector—set to some other position to abort update.

16-16. LEFT-RIGHT STEERING SIGNALS

Flying shortest distance to destination from present position:

a. DISPLAY selector—XTK/TKE.

b. MODE SEL—DPLR.

c. Fly helicopter in direction of course deviation pointer on vertical situation indicator (VSI) to center the pointer, or course deviation bar on horizontal situation indicator (HSI).

16-17. TGT STOR (TARGET STORE) OPERATION

Two methods may be used for target store operation. Method 1 is normally used when time is not available for preplanning a target store operation. Method 2 is used when time is available and it is desired to store a target in a specific DEST DISP position.

a. *Method 1.*

(1) TGT STOR pushbutton—press when flying over targets.

(2) Present position is automatically stored and the destination location is that which was displayed in the target store indicator (position 6, 7, 8, or 9) immediately before pressing the TGT STOR pushbutton.

b. *Method 2.*

(1) MODE selector—UTM or LAT/LONG, depending on coordinate format desired.

(2) DISPLAY selector—DEST/TGT.

(3) DEST DISP thumbwheel—P.

(4) KYBD pushbutton—press when over flying potential target. Display should freeze.

Note. **Do not press ENTR key while DEST DISP thumbwheel is at P.**

(5) If it is desired to store the target, turn DEST DISP thumbwheel to destination location desired and press ENTR key.

(6) If it is not desired to store the target, place DISPLAY selector momentarily to another position.

16-18. TRANSFERRING STORED TARGET COORDINATES FROM ONE LOCATION TO ANOTHER

The following procedure allows the operator to transfer stored target coordinates from one thumbwheel location to another. For example, it is assumed that the pilot wants to put the coordinates of stored target 7 into location of destination 2.

Note. **Throughout this procedure, range, time-to-go, bearing and left/right steering data are computed and displayed for the destination selected via the FLY-TO-DEST thumbwheel.**

a. DISPLAY selector—DEST TGT.

b. DEST DISP thumbwheel—7.

c. KYBD pushbutton—press.

d. DEST DISP thumbwheel—2.

e. ENTR key—press.

16-19. TRANSFERRING VARIATION FROM ONE LOCATION TO ANOTHER

The procedure to transfer variation data to the same location where the associated stored target coordinates have been transferred is the same as in paragraph 16-18 above except that the DISPLAY selector is placed at SPH/VAR.

16-20. DEAD-RECKONING NAVIGATION

As an alternate BACKUP mode, dead-reckoning navigation can be done using

groundspeed and track angle estimates provided by the operator.

a. MODE selector—BACKUP.

b. DISPLAY selector—GS/TK.

c. Best estimate of groundspeed and track angle—enter via keyboard.

d. Set MODE selector to any other position to abort procedure.

16-21. OPERATION DURING AND AFTER POWER INTERRUPTION

During a DC power interruption in flight, or when all helicopter power is removed, the random access memory (RAM) (stored destination and present position) data is retained by power from an 8.4-volt DC dry cell battery. This makes it unnecessary to reenter any navigational data when power returns or before each flight. If the battery does not retain the stored destination data during power interruption, the display will indicate an ENTR when power returns. This indicates to the pilot that previously stored data has been lost, and that present position, spheroid/variation, and destinations must be entered. The computer, upon return of power, resets present position variation to E000.0°, destination and associated variations to a non-entered state, remembers wind to zero and spheroid to CL6.

The following is a suggested checklist following battery failure:

a. Enter spheroid.

b. Enter present position variation.

c. Enter present position.

d. Enter each destination and its associated variation.

Section III. THE COMMAND INSTRUMENT SYSTEM (CIS)

16-22. GENERAL

The command instrument system being used in some Army aircraft consists of the command instrument system processor (CISP) and a CIS Mode Select panel. The instrument system provides displays for navigation and command signals on a vertical situation indicator and a horizontal situation indicator for pilot visual reference.

16-23. VERTICAL SITUATION INDICATOR

The VSI (fig 16-6) provides a cockpit display of the helicopter's pitch, roll attitude, turn rate, slip or skid, and certain navigational information. It accepts command instrument system processor signals and displays the flight command information needed to arrive at a predetermined point. The system also monitors and displays warnings when selected naviga-

tion instrument readings lack reliability. The VSI is composed of a miniature airplane; four warning indicator flags—ATT, GS, NAV, and CMD; two trim knobs—ROLL and PITCH; a bank angle scale; a bank angle index on the spheroid; a turn rate indicator and inclinometer; pitch and roll command bars; collective command pointer; a lateral deviation pointer; and a glide slope deviation pointer. Power to operate the VSI is provided from the No. 2 AC primary bus through circuit breakers marked "VIS PLT," "CPLT."

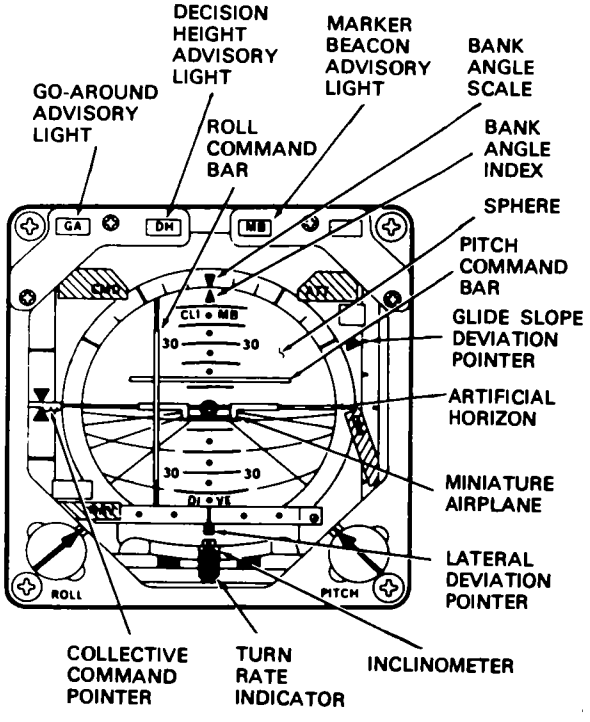


Figure 16-6. Vertical situation indicator.

16-24 STEERING COMMAND BARS AND POINTER

The roll and pitch command bars and the collective command pointer operate in conjunction with the command instrument system processor and the command instrument system/mode selector (CIS/MODE SEL). Selection of HDG on the CIS/MODE SEL panel provides a display of a roll signal by the roll command bar (fig 16-6). The pitch command bar and the collective command pointer are out of view, and the CMD flag is held from view. Selecting the CIS/MODE SEL switch NAV and the MODE SEL switch VOR ILS, the roll command bar will display roll commands from the CISP. If an ILS (LOC) frequency is tuned in, the pitch command bar and the collective command pointer will also display CISP signals. If a VOR frequency is tuned in, the pitch command bar and collective command pointer will be held from view. The CMD warning flag will be held from view, indicating that the CISP functional integrity is being monitored. Refer to figure 16-8 for VSI indications in other switch positions.

16-25 COMMAND WARNING FLAG

The command warning flag marked "CMD" is at the top left of the VSI face (fig 16-6). It is held from view when initial power is applied to the CIS processor. When any CIS mode selector switch is on and that navigation system is operating properly, the CMD flag is not in view. During operation, if the navigation signal becomes unreliable, or is lost, the CMD flag will become visible.

16-26. GLIDE SLOPE (GS) WARNING FLAG

A glide slope warning flag marked "GS" is on the right face of the indicator (fig 16-6). The letters "GS" are black on a red/white stripe background. The warning flag will move out of view when the ILS receivers are operating and reliable signals are received.

16-27. NAVIGATION WARNING FLAG

A navigation flag marked "NAV" is installed on both the VSIs and the HSIs (fig 16-6 and 16-7) to indicate when navigation systems are operating and reliable signals are being received. The VSI NAV flag is marked "NAV" with a white background and red stripes, and is on the lower left side of the indicator. The HSI NAV flag is within the compass card ring.

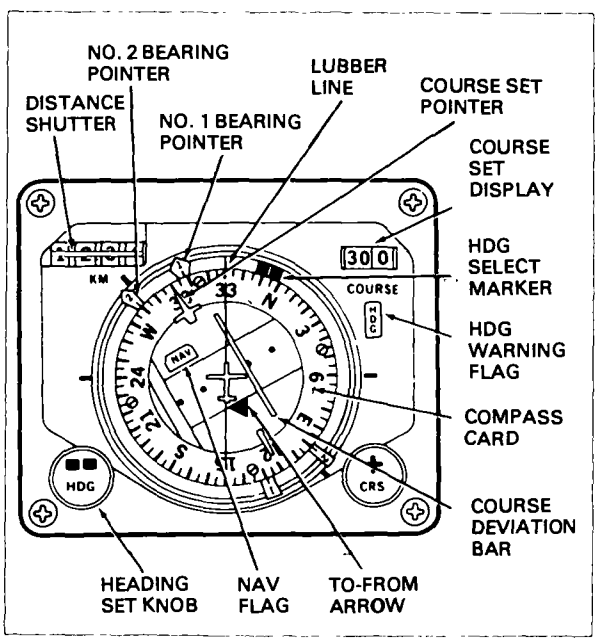


Figure 16-7. Horizontal situation indicator.

Both instrument flags will retract from view whenever a navigation receiver is on and a reliable signal is being received.

16-28. LATERAL DEVIATION POINTER

The course deviation pointer is on the VSI instrument (fig 16-6). The pointer works with the course bar on the HSI to provide the pilot with an indication of the helicopter's position with respect to the course selected on the HSI. The scales represent right or left off course. Each dot from center (on course) is 1.25° for ILS, 5° for VOR; and the pilot must fly into the needle to regain oncourse track.

16-29. GLIDE SLOPE DEVIATION POINTER

The glide slope pointer, on the right side of the VSI (fig 16-6), is used with ILS. The pointer represents the helicopter's position with respect to the glide slope. Each side of the "ON GLIDE SLOPE" (center) mark are dots, each dot representing .25° above or below the glide slope.

16-30. CONTROLS AND INDICATORS

Indicators of the VSI are on the face of the instruments. The function of each indicator is as follows:

CONTROL/ INDICATOR	FUNCTION
Miniature airplane/ horizon line	Provides reference to artificial horizon.

CONTROL/ INDICATOR	FUNCTION
Bank angle scale	Right and left 0°, 10°, 20°, 30°, 45°, 60°, and 90° of bank.
Artificial horizon	Reference of helicopter's attitude to horizon.
Turn rate indicator	4-minute turn (one-needle width either side of center), 2-minute turn (two-needle width each side of center).
Pitch and roll command bars and collective command pointer	Displays to the pilot control inputs he should make to arrive at a predetermined course, glide slope altitude, and/or vertical speed.
GA	Go-around (GA) advisory light will go on whenever the GA switch on the pilot's or co-pilot's cylic stick is pressed. The light will go off whenever the go-around mode is ended by engaging another mode on the CIS mode selector panel.
DH	Decision height (DH) advisory light will go on whenever the radar altimeter is operating and the attitude indicator is at or below the radar altitude bus setting.
MB	Marker beacon (MB) advisory light will go on and the associated marker beacon tone will be heard, depending upon volume control setting, when the helicopter is over the marker beacon transmitter.
Glide slope pointer	Displays to the pilot the position of the ILS glide slope relative to the helicopter. Pointer above center indicates aircraft is below glidepath.
Lateral deviation pointer	Displays to the pilot the position of a lateral reference (VOR, LOC, DPLR, FM HOME) relative to the helicopter.
ATT warning flag	Indicates loss of vertical gyro power or VSI malfunction.
NAV warning flag	Indicates loss or unreliable signal indication.
GS warning flag	Indicates loss or unreliable signal indicator.
PITCH trim knob	Adjust artificial horizon up (climb) or down (dive) from at least 8° to no more than 20°.
ROLL trim knob	Adjust artificial horizon right or left from at least 8° to no more than 20°.

Two HSIs (fig 16-7) are installed on the instrument panel, one in front of each pilot. The HSI consists of a compass card, two bearing-to-station pointers with back-course markers, a course bar, a KM indicator, heading set (HDG) knob and marker, a course-set (CRS) knob, a COURSE digital readout, a TO-FROM arrow, a NAV flag, and a compass HDG flag. The HSI's operating power is taken from the No. 2 AC primary bus through a circuit breaker marked "HSI PLT/CPLT."

Controls of the horizontal situation and indicators (fig 16-7) are as follows:

CONTROL/ INDICATOR	FUNCTION
Compass card	The compass card is a 360-degree scale that turns to display heading data obtained from the compass control. The helicopter headings are read at the upper lubber line.
Bearing pointer No. 1	The pointer operates in conjunction with doppler. Indicates relative bearing to doppler destination set on FLY-TO-DEST thumbwheel.
Bearing pointer No. 2	The pointer operates in conjunction with selected VOR or automatic direction finder (ADF) receiver. The pointer is read against the compass card and indicates the magnetic bearing to the VOR or ADF station.
Course deviation bar	This bar indicates lateral deviation from a selected course. When the helicopter is flying the selected course, the course bar will be alined with the course set pointer and will be centered on the fixed aircraft symbol.
CRS knob	CRS knob and the course set counter operate in conjunction with the course pointer and allow the pilot to select any of 360 courses. Once set, the course pointer will turn with the compass card and will be centered on the upper lubber line when the helicopter is flying the selected course.
KM indicator	Digital distance balance display in kilometers to destination set on doppler DEST DISP.
HDG knob	HDG knob operates in conjunction with the heading select marker, allows the pilot to select any one of 360 headings. Seven full turns of the knob produces a 360-degree turn of the marker.
TO-FROM arrow	TO-FROM arrow indicates that the helicopter is flying to or away from a selected VOR.
NAV flag	The NAV flag at the top of the TO indicator turns with the compass card. The flag will retract from view when a reliable navigation signal is being applied to the instrument.

16-33. VSI/HSI AND CIS MODE SELECTOR PANEL

The mode select panels (fig 16-8) are integrally lighted instrument panel mounted controls for the VSI, HSI, and CISP. The CISP processes navigation signals supplied by the associated helicopter systems into pitch, roll, and collective steering commands that are displayed on the VSI; presents the modes of operation and corresponding presentations. Those commands allow the pilot to fly the helicopter along the desired flightpath. Power to operate the pilot's MODE SEL is taken from the No. 2 DC primary bus through a circuit breaker marked "PILOT MODE SELECT." The copilot's MODE SEL takes power from the No. 1 DC primary bus through a circuit breaker marked "COPILOT MODE SELECT."

TURN PAGE FOR CIS MODES OF OPERATION

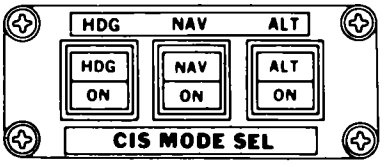
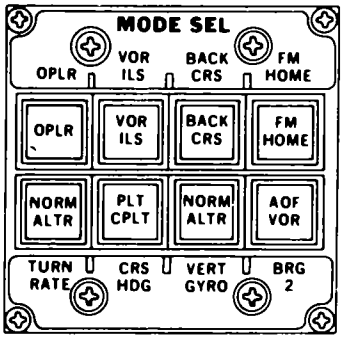
MODE OF OPERATIONS	 CIS MODE SELECTOR	 HSI/VSI MODE SELECTOR
NONE	NONE	ANY
MANUAL HEADING	HDG	ANY
ALTITUDE HOLD	ALT	ANY
VOR NAVIGATION	NAV	VOR
ILS NAVIGATION	NAV	ILS
ILS APPROACH	NAV	ILS
ILS DECELERATION	NAV	ILS
ILS BACK COURSE	NAV	BACK CRS
LEVELOFF	NAV	VOR/ILS/BACK CRS
GO-AROUND	NAV	VOR/ILS
DOPPLER	NAV	DPLR
FM HOMING	NAV	FM HOME

Figure 16-8. CIS modes of operation.

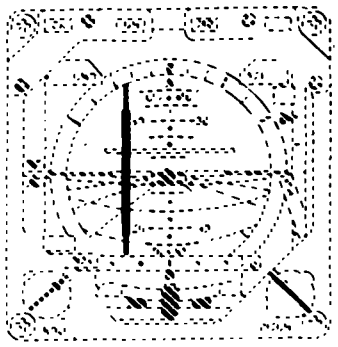
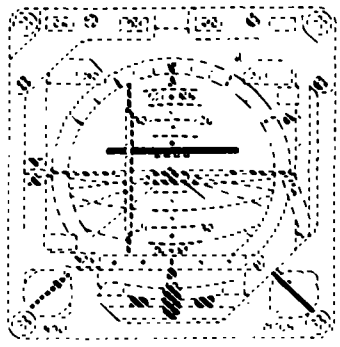
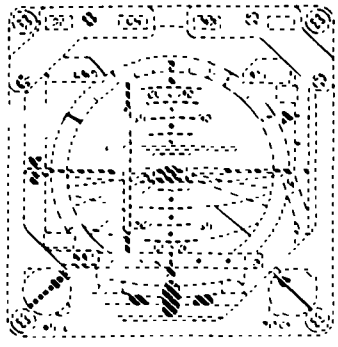
 CYCLIC ROLL COMMAND BAR	 CYCLIC PITCH COMMAND BAR	 COLLECTIVE COMMAND POINTER
OFF SCALE	OFF SCALE	OFF SCALE
PROCESSED CYCLIC ROLL COMMAND	OFF SCALE	OFF SCALE
OFF SCALE	OFF SCALE	PROCESSED COLLECTIVE COMMAND
PROCESSED CYCLIC ROLL COMMAND	OFF SCALE	OFF SCALE
PROCESSED CYCLIC ROLL COMMAND	PROCESSED CYCLIC PITCH COMMAND	PROCESSED COLLECTIVE COMMAND
PROCESSED CYCLIC ROLL COMMAND	PROCESSED CYCLIC PITCH COMMAND	PROCESSED COLLECTIVE COMMAND
PROCESSED CYCLIC ROLL COMMAND	PROCESSED CYCLIC PITCH COMMAND	PROCESSED COLLECTIVE COMMAND
PROCESSED CYCLIC ROLL COMMAND	OFF SCALE	OFF SCALE
PROCESSED CYCLIC ROLL COMMAND	OFF SCALE OR PROCESSED CYCLIC PITCH COMMAND	PROCESSED COLLECTIVE COMMAND
PROCESSED CYCLIC ROLL COMMAND	PROCESSED CYCLIC PITCH COMMAND	PROCESSED COLLECTIVE COMMAND
PROCESSED CYCLIC ROLL COMMAND	OFF SCALE	OFF SCALE
PROCESSED CYCLIC ROLL COMMAND	OFF SCALE	OFF SCALE

Figure 16-8. CIS modes of operation (cont)

[redacted]

Controls of the mode selector panel (fig 16-8) are as follows:

CONTROL/ INDICATOR	FUNCTION
VSI/HSI Mode Selector	
DPLR	Directs doppler lateral deviation and NAV flag signals to VSIs and HSIs.
VOR ILS	Directs VOR or ILS signals to VSIs and HSIs. Provides a signal to NAV flag.
BACK CRS	Reverse polarity of back course signal to provide directional display for VSIs and HSIs. Provides a signal to NAV flag.
FM HOME	Directs FM homing deviation and flag signals to VSIs.
TURN RATE NORM	Provides pilot and copilot with his own turn rate gyro information displayed on his VSI.
ALTR	Allows copilot's turn rate gyro information to be displayed on pilot's VSI, or pilot's gyro information display on copilot's VSI.
CRS HDG PLT	Provides for pilot's omnibearing selector to be connected to navigation receiver and concurrent connection of pilot's HSI course datum and heading datum output to command instrument system processor.
CPLT	Provides for copilot's omnibearing selector to be connected to navigation receiver and concurrent connection of copilot's HSI course datum and heading datum output to command instrument system processor.
VERT GYRO NORM	Provides pilot and copilot with his own vertical gyro information displayed on his VSI.
ALTR	Allows copilot's vertical gyro information to be displayed on pilot's VSI, or pilot's gyro information to be displayed on copilot's VSI.
BRG2 ADF	Allows pilot or copilot to select ADF on his No. 2 bearing pointer, each independent of the other.
VOR	Allows pilot or copilot to select VOR on his No. 2 bearing pointer, each independent of the other.
CIS Mode Selector	Selects one of three modes of operation to direct navigational signals to the CISP for command signal display.
HDG ON	Direct heading and roll signals to CIS processor for steering commands that will allow pilot to maintain a selected heading.
NAV ON	Gives heading commands to acquire and track a selected VOR, ILS, DPLR, or FM intercept, or to acquire and track glide slope beam.
ALT ON	Directs barometric pressure signals and collective stick position signals to CIS processor.

[redacted]

The command instrument system OFF mode (no switch legends lit) causes the cyclic roll, cyclic pitch, and collective command pointers on both vertical situation indicators to be stored out of view and the command warning flag of both VSIs to be biased out of view. The CISP is in the OFF mode upon initial application of electrical power, before the pilot selects either HDG, NAV, or ALT mode on the CIS mode selector. When NAV mode is selected the CISP remains in the OFF mode unless the DPLR, VOR ILS, or FM HOME navigation data has been selected on the pilot's VSI/HSI mode selector. The CISP will return to the OFF mode whenever the HDG, NAV, and ALT hold modes are disengaged as indicated by the respective ON legends going off, or by turning off the associated navigation receiver. Separate modes are manually disengaged by pressing the mode switch when ON is lit.

[redacted]

The heading mode processes the heading error and roll attitude signals to supply a limited cyclic roll command, which, when followed, causes the helicopter to acquire and track the heading manually selected on either pilot's HSI. The processed signal causes the VSI cyclic roll command pointer to deflect in the direction of the required control response; i.e., pointer deflection to the right indicates a coordinated right turn is required. When properly followed, the command results in not more than one overshoot in acquiring the selected heading and a tracking error of not more than 2°. The processor gain provides 1° of roll command for each degree of heading error up to a roll command limit of 20°. The CISP heading mode is engaged by momentarily pressing the HDG switch on the pilot's CIS mode selector, or as described in paragraph 16-38.

[redacted]

The altitude hold mode processes barometric pressure signals from the air data transducer in addition to the collective stick position signal. When the ALT switch on the pilot's CIS mode selector is pressed, the CISP provides collective command signals, which, when properly followed, cause the helicopter to maintain altitude to within plus or minus 50 feet. The altitude hold mode synchronizes on the engagement altitude for vertical rates up to 200 feet per minute (fpm) and provides performance for altitude inputs between -1000 and +10,000 feet at airspeeds from 70 to 150 knots indicated airspeed (KIAS). It is possible to engage the altitude hold mode, regardless of whether the heading mode or navigation mode is engaged, except that the CISP logic prevents manual selection of the altitude hold mode whenever the NAV mode is engaged and an ILS frequency is selected. This prevents the operator from selecting altitude hold mode during an instrument approach. The altitude hold mode is manually engaged by pressing the ALT hold switch (subject to above restriction) or automatically engaged as described in paragraph 16-40. The altitude hold mode may be manually disengaged by pressing

the ALT hold switch when the ON legend is lit. Altitude hold may be disengaged also by selecting any other mode which takes priority (e.g., Go-Around).

16-33. NAVIGATION MODE

The navigation mode causes the CISP to enter the VOR NAV, ILS NAV, DPLR NAV, or FM NAV mode according to the navigation data preselected on the VSI/HSI mode selector. During the navigation mode, the CISP provides steering commands based on the navigation signals displayed on the pilot's VSI. The CISP navigation mode is engaged by pressing the NAV switch on the CIS mode selector.

16-34. VOR NAV MODE

The VOR NAV mode is established by selecting the VOR/ILS switch on the VSI/HSI mode selector and pressing the NAV switch on the CIS mode selector. The CISP processes the heading and course signals derived from either the pilot's or the copilot's HSI in addition to the lateral deviation and lateral flag signals applied to the pilot's VSI. The CISP provides a limited cyclic roll command, which, when followed, shall cause the helicopter to acquire and track the course setting manually selected on the HSI. Engagement of the VOR NAV when the helicopter position is in excess of 10° to 12° from the selected radial will cause the initial course intersection to be made in the heading mode as described in paragraph 16-34. The CISP logic will light the CIS mode selector HDG switch ON legend during the initial course intersection. When the helicopter is within 10° to 20° of the selected course, the CISP beam sensor will capture the VOR lateral beam. The processor logic will turn off the HDG switch ON legend and the final course cut, acquisition, and tracking will be based on the VOR lateral deviation signals. The processor causes the roll command pointer to deflect in the direction of the required control response. When properly followed, the command will result in not more than one overshoot at a range of 10 NM at a cruise speed of 100 $\pm$ 10 knots, and not more than two overshoots at ranges between 5 and 40 NM at speeds from 70 to 140 knots. When passing over the VOR station, the CISP reverts to a station passage submode and remains in this submode for 30 seconds. Cyclic roll commands during the station passage submode will be obtained from the HSI course datum signal. Outbound course changes may be implemented by the HSI CRS SET knob during the station passage submode. Course changes to a new radial, or identification of VOR intersections, may be made before station passage by setting the HSI HDG control to the present heading and actuating the HDG switch. This will disengage the NAV mode and allow the pilot to continue on the original radial in the heading mode. A VOR intersection fix or selection of a new radial course may be made without effecting the CIS steering commands. Actuating the NAV switch reengages the VOR NAV

mode to either continue on the original VOR radial or to initiate an intercept to the new selected radial.

The instrument landing system NAV mode is established by selecting the VOR/ILS switch on the VSI/HSI mode selector, tuning a localizer frequency on the navigation receiver and actuating the NAV switch in the pilot's CIS mode selector. During the ILS NAV mode, the CISP processes the following signals in addition to those processed during the VOR NAV mode: (1) The vertical deviation and vertical flag signals, (2) the indicated airspeed (IAS) and barometric altitude signals, and (3) the collective stick position sensor and helicopter pitch attitude signals. The indicated airspeed and pitch attitude signals are processed to provide a limited cyclic pitch command, which, when properly followed, will result in maintaining an airspeed that should not deviate more than 5 knots from the IAS existing at the time the ILS NAV mode is engaged. The BAR ALT and collective stick position signals are processed to provide a limited collective command, which, when properly followed, will cause the helicopter to maintain the altitude existing at the time the ILS NAV mode is engaged. The collective command pointer will deflect in the direction of the required control responses, i.e., an upward deflection of the collective pointer indicates a descent is required. The CISP will cause the ALT hold switch ON legend to light whenever the altitude hold mode is engaged. Actuating the ALT hold ON switch will disengage the altitude hold mode. Desired course must be set on selected HSI CRS window and CRS HDG switch, PLT or CPLT as applicable. The initial course intersection and the localizer course cut, acquisition, and tracking will be done as described for the VOR NAV mode except that not more than one overshoot at a range of 10 NM at 100 $\pm$ 10 KIAS, and not more than two overshoots at ranges between 5 and 20 NM for airspeeds between 70 and 130 KIAS should occur.

The approach mode, a submode of the ILS NAV mode, will be automatically engaged when the helicopter captures the glide slope. During the approach mode, the CISP processes the vertical deviation, GS flag, and collective stick position signals to provide a limited collective command, which, when properly followed, shall cause the helicopter to acquire and track the glide slope path during an approach to landing. When the glide slope is intercepted, the CISP logic disengages the altitude hold mode and causes the ON legend of the ALT hold switch to go off. The CISP will provide a down movement of the collective command steering pointer to advise the pilot of the transition from altitude hold to glide slope tracking, and to assist in acquiring the glide slope path. The bias input has a washout time of 10 $\pm$ 5 seconds. The cyclic roll commands are limited to $\pm$ 15° during the approach submode. When properly followed, the roll commands will result in the helicopter tracking the localizer to an approach. The

collective commands, when properly followed, will result in not more than one overshoot in acquiring the glidepath and have a glidepath tracking free of oscillations. The cyclic roll and collective steering performance is applicable for approach airspeed from 130 KIAS down to 50 KIAS.

16-42. BACK CRS MODE

The back course mode is a submode of the ILS NAV mode and is engaged by concurrent ILS ON and BACK CRS ON signal from the pilot's HSI/VSI mode selector. The CISP monitors the localizer lateral deviation signals to provide cyclic roll commands, which, when properly followed, will allow the pilots to complete back course localizer approach in the same manner as the front course ILS. Since no glide slope is available on the back course ILS, ALT hold must be manually turned off. The desired back course runway heading must be set on the selected HSI CRS window.

16-43. LEVELOFF MODE

WARNING. The use of radar altimeter settings for leveloff commands in the VOR NAV mode could lead to a safety of flight condition if lower terrain is on the approach end of the runway and the pilot fails to monitor the barometric altitude. In this mode, barometric altitude must be used for determination of MDA or DH.

The leveloff mode will be activated when either the VOR NAV or ILS NAV modes are engaged, and will be deactivated by selection of another mode or when a radar altitude valid signal is not present. The leveloff mode is not a function of a VOR or ILS CIS approach. During ILS or VOR approaches, the barometric altimeter must be used to determine arrival at the minimum descent altitude (MDA). The leveloff mode provides the pilots with a selectable low altitude command which is used primarily in tactical environments where detailed map reconnaissance is conducted before instrument meteorological conditions. This mode is automatically engaged when the radar altitude goes below either the pilot's or copilot's radar altimeter low altitude warning bug setting, whichever is at the higher setting. A DH legend on the VSI and a LO light display on the radar altimeter indicator goes on whenever the radar altitude is less than the LO bug setting. The CISP monitors the radar altimeter and the collective stick position sensor to provide a collective pointer command, which, when properly followed, will cause the helicopter to maintain an altitude within 10 feet of the low altitude setting for settings below 250 feet, and 20 feet for settings above 250 feet. The CISP causes the ALT switch ON legend to light and the altitude hold mode to be engaged.

16-44. GO-AROUND MODE

The go-around mode processes roll and pitch attitude, altitude rate, collective stick position, and airspeed inputs in addition to internally generated airspeed and vertical

speed command signals to provide cyclic roll, cyclic pitch, and collective commands. The go-around mode will engage when either pilot presses the GA (Go-Around) switch on his cyclic control grip. When the go-around mode is engaged, the CISP immediately provides a collective pointer command, which, when followed, will result in a 500 $\pm$ 50 fpm rate-of-climb at zero bank angle. Five seconds after the GA switch is pressed, the CISP will provide cyclic pitch bar commands, which, when followed, will result in 80-KIAS for the climbout. The go-around mode is disengaged by changing to any other mode on the pilot's CIS mode selector or VSI/HSI mode selector.

16-45. DOPPLER MODE

The doppler navigation mode is engaged by selecting the DPLR switch on the VSI/HSI mode selector and the NAV switch on the CIS mode selector. During the doppler navigation mode, the CISP processes doppler track angle error and the doppler NAV flag signals in addition to the roll angle input from the attitude gyro. The CISP provides cyclic roll bar commands, which, when followed, result in a straight line, wind corrected, flight over distances greater than 0.2 kilometer from the destination. The DPLR NAV logic detects the condition of station passover, and automatically switches to heading mode. The switch to heading mode will be indicated by the HDG switch ON legend being turned on, and the NAV switch ON legend being turned off. The doppler navigation mode will not automatically reengage, but will require manual reengagement of the NAV switch on the CIS mode selector.

16-46. FM HOME MODE

The FM homing (fig 16-8) is engaged by selecting the FM HOME switch on the pilot's VSI/HSI mode selector and the NAV switch on the pilot's CIS mode selector. Selecting FM homing on the VSI/HSI mode selector directs FM homing signals only to the VSI. Other NAV modes will be retained on the HSI if previously selected. During the FM HOME mode, the CISP processes the lateral deviation and flag signals displayed on the pilot's VSI in addition to the roll angle input from the attitude gyro. The CISP filters and dampens the FM homing deviation signals and provides cyclic roll commands to aid the pilot in homing on a radio station selected on the No. 1 VHF-FM communications receiver. When properly followed, the roll commands result in not more than two overshoot heading changes before maintaining a tracking error not to go over 3°. The CISP will revert to the heading mode whenever the lateral deviation rate is over 1.5° per second for a period of over 1 second. The CISP will cause the CIS mode selector HDG switch ON legend to light, and remain in the heading mode until the FM mode or some other mode is manually selected. Concurrent VOR and FM or concurrent DPLR and FM mode inputs will be considered an FM mode input to the CISP.

[redacted]

The turn rate gyro selection provides each pilot the option of having his VSI display his own turn rate gyro signal (NORM operation) or of having the other pilot's turn rate gyro signal displayed (ALTR operation). The turn rate gyro selection is independent of the navigation modes selected by the top row of switches and is independent of which turn rate gyro the other pilot has selected. The NORM selection connects each pilot's VSI to his own turn rate gyro. The selection of NORM or ALTR operation is indicated by lighting the respective legend on the TURN RATE selector switch. The lamp power to the indicator legends is controlled through a relay so that the NORM legend is lit in case the mode selector logic or lamp drivers fail. Sequential operation of the TURN RATE switch alternates the rate gyro connected to the VSI.

[redacted]

The CRS HDG switch on the mode selector provides for either the pilot's or the copilot's course selector to be connected to the navigation receiver, and for concurrent connection of the same pilot's HSI course and heading information to the command instrument system processor. The CRS resolver is normally connected to the pilot's HSI until selected by the copilot on his mode selector. CRS HDG control is transferred by pressing the CRS HDG switch. The pilot having the CRS HDG control is indicated by lighting of either the PLT or the CPLT legend on each mode selector. When power is first applied to the mode selector, the pilot's position is automatically selected. The CRS HDG selection is independent of the navigation modes selected by the top row of switches.

[redacted]

The vertical gyro selection provides each pilot the option of having his VSI display his own vertical gyro attitude (NORM operation) or of having the other pilot's vertical gyro attitude displayed (ALTR operation). The vertical gyro selection is independent of the navigation modes selected by the top row of switches and is independent of which vertical gyro the other pilot has selected. Each pilot's VSI is normally connected to his own vertical gyro. The selection of NORM or ALTR operation is indicated by lighting the respective legend on the VERT GYRO selector switch. The lamp power to the indicator legends is controlled through a relay so that the NORM legend is lit in case the mode selector logic or lamp drivers fail. Sequential operation of the VERT GYRO switch alternates the vertical gyro connected to the VSI.

[redacted]

The HSI No. 2 bearing pointer selection allows the option of either the LF/ADF

bearing or the VOR bearing to a selected station. The ADF/VOR selection is independent of the navigation modes selected by the top row of switches, and either pilot selects ADF or VOR, independent of the other pilot's selection. The No. 2 bearing pointer is normally connected to the LF/ADF bearing output. The selection of either ADF or VOR bearing is indicated by lighting of the respective legend on the selector switch. The lamp power to the indicator legends is controlled through a relay so that the ADF legend is lit in case the mode selector logic or lamp drivers fail. Sequential operation of the ADF/VOR switch alternates the bearing source connected to the No. 2 bearing pointer between ADF and VOR.

16-51. OPERATION

a. *Heading Hold.*

(1) CIS MODE SEL switch—HDG.

(2) HDG set knob on HSI—set as desired.

(3) Selected heading is achieved by banking helicopter to center roll command bar.

b. *VOR Course Intercept.*

(1) Frequency—set.

(2) HSI CRS set knob—set to desired course.

(3) CIS mode selector switch—NAV.

(4) Follow roll command bar to initially follow intercept heading and then follow command bar to intercept VOR course.

c. *ILS Approach.*

(1) Frequency—set.

(2) HSI CRS set knob—set to desired course.

(3) LO altitude bug—set to missed approach point height above terrain (HAT).

(4) CIS MODE SEL—NAV.

(5) At two dots localizer deviation on HSI, follow roll command bar to intercept localizer.

(6) As glide slope deviation pointer centers, follow collective commands for glide slope tracking.

(7) At decision height, press GA switch for go-around mode if breakout has not occurred.

d. *Back Course Localizer Approach.*

(1) Frequency—set.

(2) LO altitude bug—set to missed approach point HAT.

(3) Set up DH using SET bug on pilot radar altimeter.

(4) HSI CRS set knob—set to inbound backcourse.

(5) CIS MODE SEL—NAV.

(6) MODE SEL—BACK CRS.

(7) Fly same as front course (para 16-51c(5)). Turn off MODE SEL ALT legend to store collective command pointer before making manual descent on back course appraoch.

CHAPTER 17

THE INERTIAL NAVIGATION SET AN/ASN-86

Section I. GENERAL

17-1. INTRODUCTION

a. This chapter provides a reference for the use of the inertial navigation set AN/ASN-86 and includes a discussion of its theory of inertial navigation and its operation capabilities.

b. Unlike other methods of navigation, inertial guidance does not rely on observations of land or stars, radio or radar signals, or any information from outside the vehicle. An inertial navigator continually determines desired information from measurements made entirely within the vehicle. Completely independent of its environment, the inertial system provides velocity information accurately and instantaneously for all maneuvers. It also provides an accurate attitude and heading reference. With an inertial system, the use of other gyros becomes unnecessary except for backup purposes, and other aircraft equipment can make use of the accurate reference information to increase the overall capabilities of the aircraft.

[redacted]

The instruments used within an inertial navigator basically consist of gyroscopes that stabilize the platform, accelerometers that measure changes in velocity (acceleration), and a computer which uses the information from the navigator to continuously calculate the vehicle's position and guide it on course. Although complex electronic circuits are required to operate the accelerometers and gyroscopes, the inherent ease of operation of an inertial navigator gives it many advantages over earlier navigation systems.

Section II. PRINCIPLES OF INERTIAL NAVIGATION

[redacted]

a. The basic principle of an inertial navigation system is the measurement of acceleration in an earth reference coordinate frame.

b. The basic measuring instrument of displacement is the accelerometer, an instrument which measures the acceleration of the vehicle which carries it. It consists of a pendulous mass that is free to rotate about a pivot axis in the instrument. Figure 17-1 shows one form of this device. It has an electrical pickoff which converts the rotation of the test mass about the pivot axis to an output signal. An acceleration of the device to the right causes the pendulum to swing to the left, thereby providing an electrical pickoff signal which causes a torquer to restrain the pendulum. The pickoff signal is fed to a high gain amplifier and the output of this amplifier is connected to the torquer on the accelerometer (fig 17-1). The operation of this feedback loop is such that when an acceleration is present, a voltage is sent back to the torquer which is precisely sufficient to hold the pickoff signal at its null under the influence of the measured acceleration. This voltage fed to the torquer is proportional to the measured acceleration and provides the electrical output acceleration signal which is then passed to the navigation computer.

c. The accelerometer portion of the system cannot distinguish between actual acceleration and the force of gravity. Therefore, if the accelerometer is tilted off level (fig 17-2), its output will include a

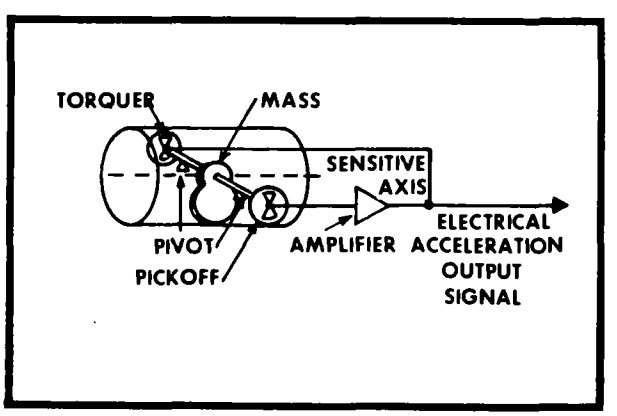


Figure 17-1. Torque-balanced accelerometer.

component of the gravity force as well as the vehicle acceleration. To obtain the correct vehicle acceleration in the horizontal plane, it is necessary to hold the accelerometer level.

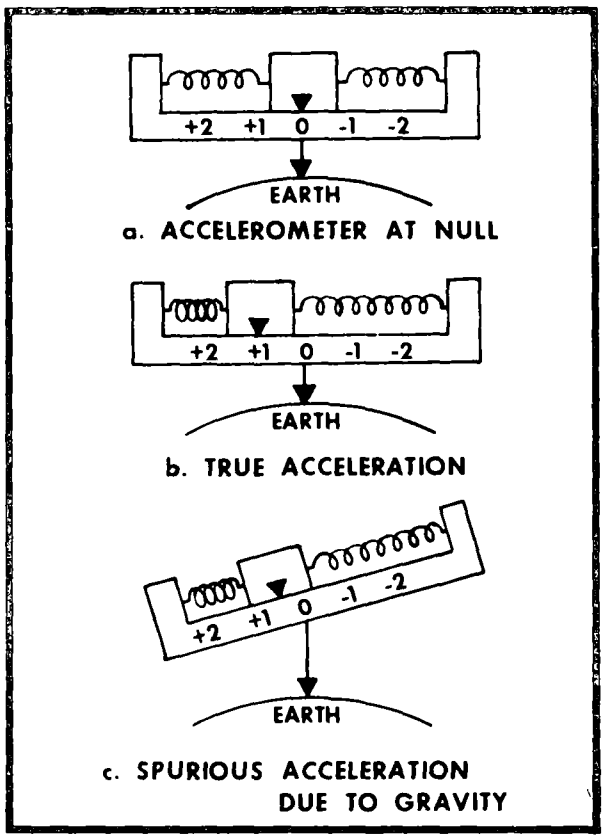


Figure 17-2. Principle of accelerometer.

d. If the accelerometer is mounted in a vehicle in such a way that it is always held level, it will measure the true acceleration of the vehicle in a horizontal direction, along the axis of the accelerometer. By mounting another level accelerometer perpendicular to the first one, the total true acceleration of the vehicle in a horizontal plane can be determined at all times.

17-4. THE INTEGRATORS

In order to convert the measured acceleration to vehicle position information, it is necessary to process acceleration signals to produce velocity information, and then to process velocity information to obtain distance traveled. Accelerations are converted to pulsed increments of velocity by the quantizers in the platform. The pulses are summed in the computer, and the sum comprises the first integration of acceleration to velocity. The accumulated velocity in the east-west (E-W) and

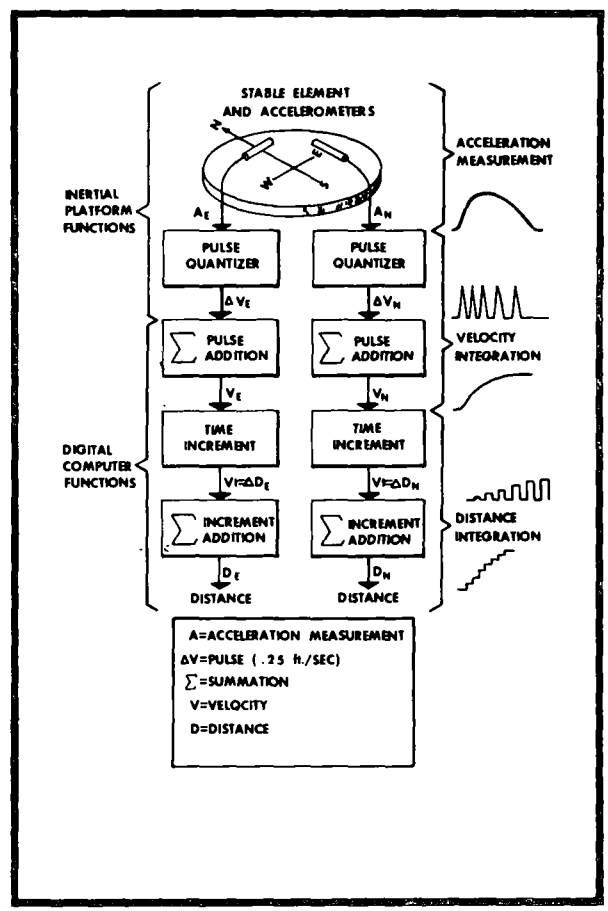


Figure 17-3. Inertial distance measurement.

north-south (N-S) directions is multiplied by the time increments between the computer iterations. These in turn are summed in the computer, and this second sum now comprises the integration of velocity into distance (fig 17-3).

17-5. TOTAL DISTANCE TRAVELED

If a means exists for always pointing one of the level accelerometers toward the north, the other one will always point toward the east. By connecting the accelerometers together with integrators (fig 17-3), distance traveled in the north-south and east-west directions can be determined. The importance of maintaining the proper accelerometer pointed north and the proper accelerometers level with the surface of the Earth is apparent. If the accelerometers were to tilt off level, components of the gravity force would be measured and navigation errors would result. This leads to the need for the next basic part of the inertial navigation system—the gimbaled stable element.

17-6. GYROSCOPE AND GIMBAL SYSTEM—THE STABLE ELEMENT

a. The proper orientation of the accelerometers is maintained by mounting them on a platfrom together with gyroscopes which are used as sensing elements to control the platform orientation. A platform which is controlled by gyros in this way is referred to as a stable element. The platform is mounted in gimbals which isolate the platform from angular motions of the aircraft.

b. The stable element is made up of two identical floated 2-degree-of-freedom gyroscopes mounted one on top of the other in a dumbbell configuration with their spin axes horizontal and at right angles to each other. The wheels in these gryoscopes spin at high speed and resist any effort to change their orientation; that is, once up to speed, the wheels will tend to remain in their original orientation in inertial space. Figure 17-4 shows a simple diagram of a 2-degree-of-freedom gyro. The pickoffs on the gimbals within the gyro produce electrical signals if the gyro case is moved from its null position and with respect to the wheel. With the gyros mounted on the

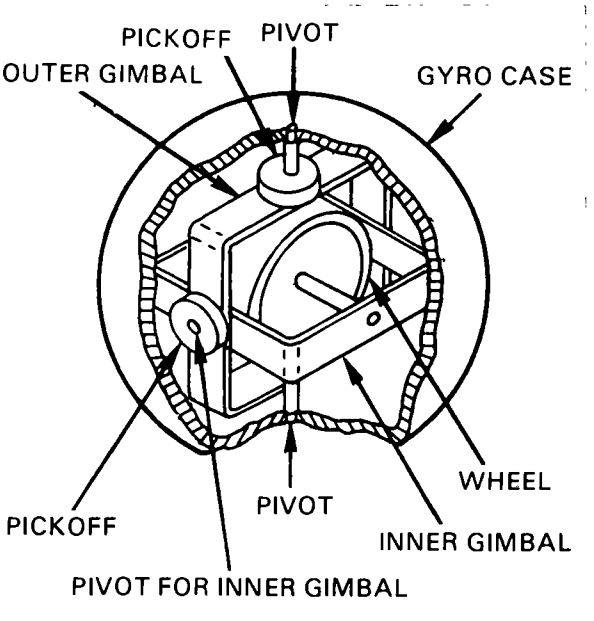


Figure 17-4. Gyro with two gimbals proving 2 degrees of freedom.

stable element, any displacement of the stable element from the frame of reference will be sensed by these electrical pickoffs in the gyroscopes. The signals thus created are used to drive platform gimbals to realine the stable element. The operation of the gimbal driving system is illustrated by the simplified single-axis, gyro-stabilized platform shown in figure 17-5.

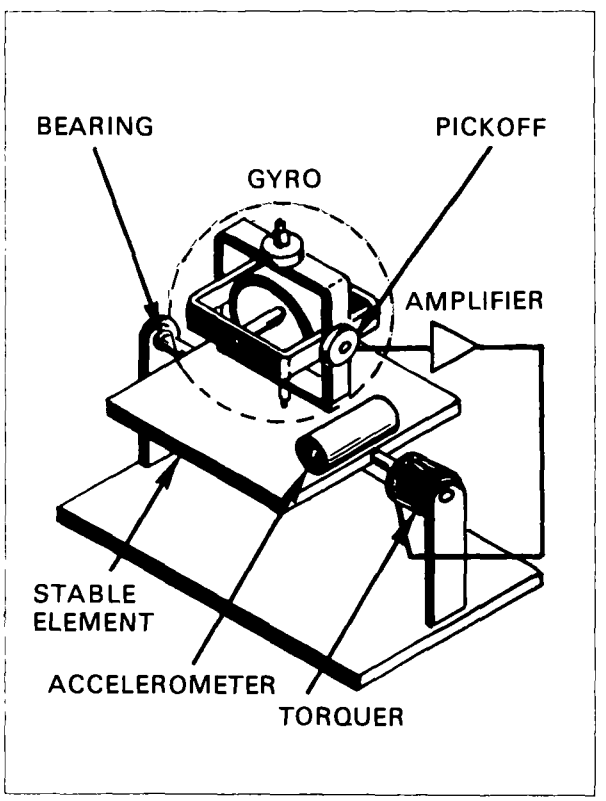


Figure 17-5. Single-axis, gyro-stabilized platform.

c. Figure 17-6 illustrates the four-gimbal platform configuration actually used in the inertial navigation system. The stable element is mounted in the gimbal structure so that regardless of which maneuvers are made by the aircraft, it retains its original orientation, thus serving as a level mount for the accelerometers. An azimuth gimbal permits the aircraft to change heading without affecting the orientation of the stable element, a pitch gimbal removes the effect of aircraft pitch, and a roll gimbal does away with the effects of roll. An extra roll gimbal is provided which prevents the occurrence of a condition known as *gimbal lock* during certain aircraft maneuvers and makes the system truly all attitude. The gimbals are so oriented that aircraft attitude and heading may be sensed by measuring angles between the gimbals. Synchros transmit this information to the attitude indicator and other systems in the aircraft.

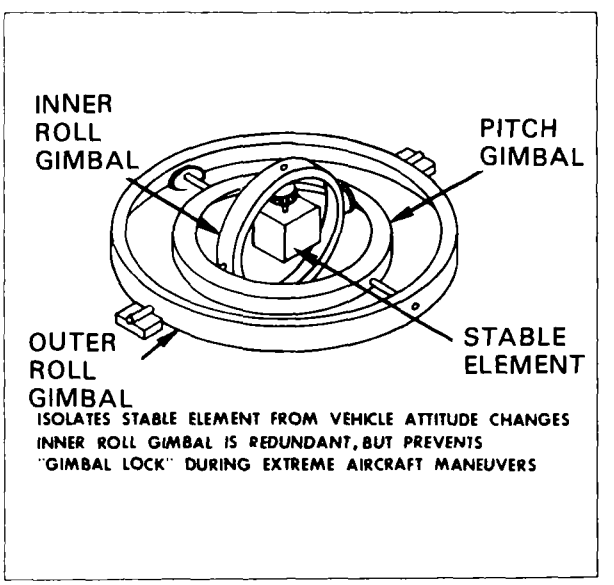


Figure 17-6. Typical gimbal suspension.

17-7. EFFECT OF A SPHERICAL ROTATING EARTH

a. Figure 17-7 illustrates the apparent rotation of a stabilized platform located at

the Equator. As shown, the platform will remain fixed with respect to the surface of the Earth as the Earth spins around its polar axis. This is undesirable from the point of view of navigation since the accelerometers will not remain level with respect to the direction of gravity. Consider also what happens to a stable element which is alined properly at the beginning of a flight as the aircraft flies over the surface of the Earth. If the aircraft flightpath is straight north from the Equator to the North Pole as in (a) on figure 17-8, the aircraft sees a continuing pitch maneuver. At the pole, instead of the platform being level with inertial space, it would now be tilted 90° off level.

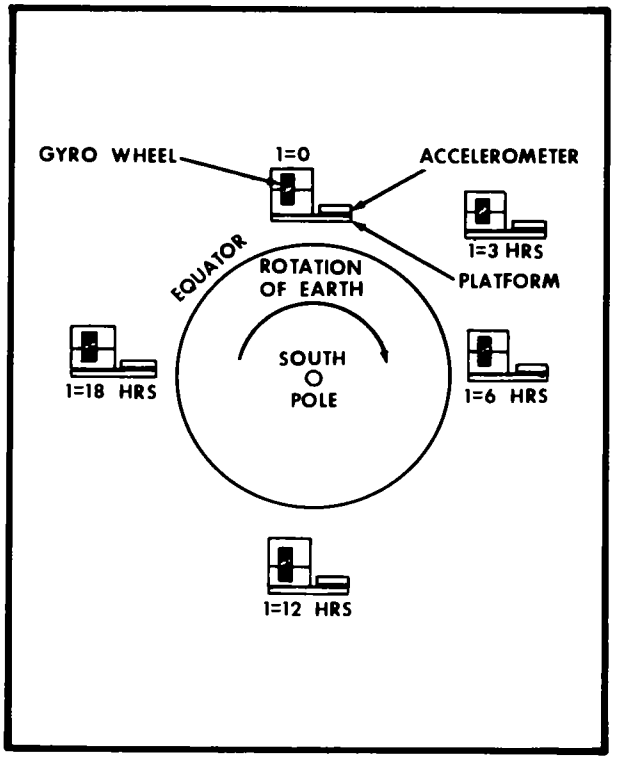


Figure 17-7. Stationary gyro-stabilized platform without Earth-rate torquing.

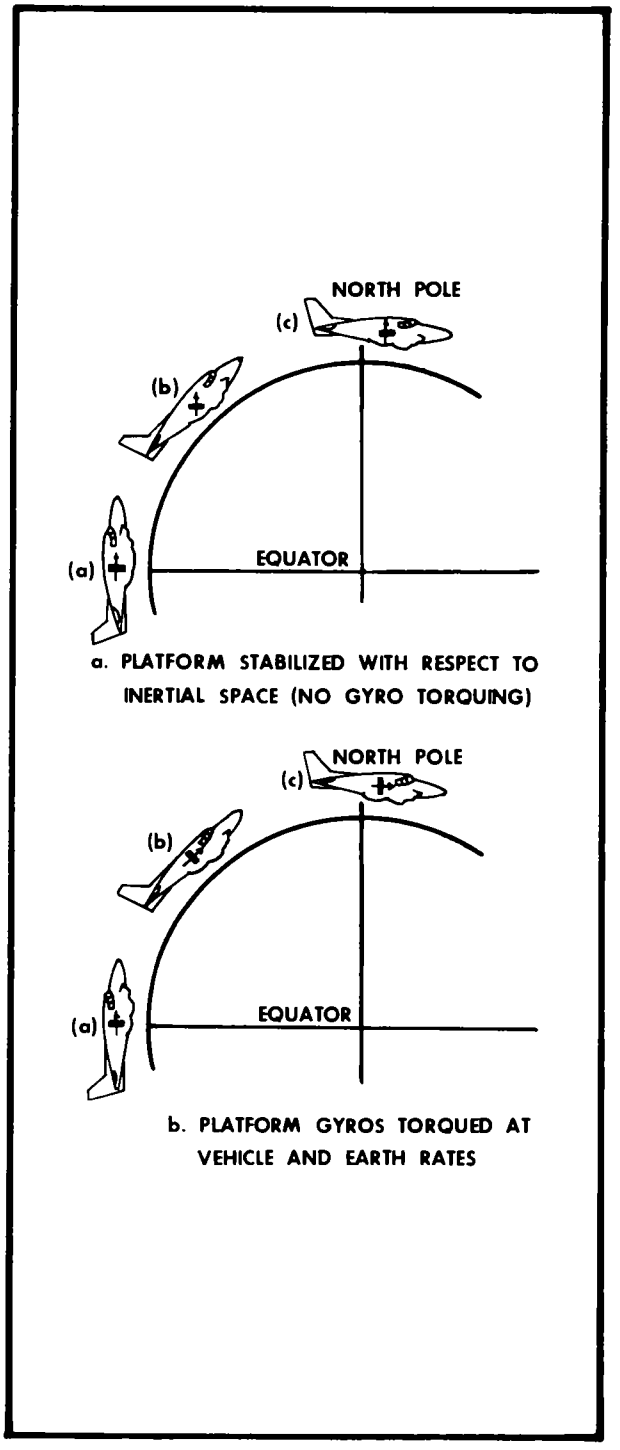


Figure 17-8. Platform attitude in moving aircraft with and without gyro torquing.

b. To overcome these problems, another property of a gyro is used—that of precession. If a force is applied to an axis of a spinning gyro wheel, and the wheel, through a gimbaling structure, is free to move, it will move about an axis at right angles to the axis about which the force is applied. Applying this principle, as an aircraft flies over the Earth and as the Earth rotates, it is possible to apply a continuous torque (or force) to the appropriate axes by electromagnetic elements called torquers, thereby reorienting the gyro wheels to maintain the stable element level with respect to the Earth and pointed north. An electronic computer unit is used to develop the signals necessary to properly torque the gyros. The corrections for rotation of the Earth and travel of the aircraft depend on aircraft position. Exact corrections are computed to maintain the platform level and oriented north as the Earth rotates and the aircraft moves around it. The computer also corrects for spurious accelerations due to Coriolis effect and the oblateness of the Earth.

17-8. THE SCHULER PENDULUM AND AIRCRAFT TRAVEL

a. The torquing necessary to maintain the stable element level with respect to the gravity vector as the aircraft flies over the surface of the Earth is referred to as *vehicle rate torquing*. The mechanization of this torquing leads to a computing loop which is said to be "Schuler tuned." This computing loop (which is the same for each platform axis) is shown in "a" of figure 17-9.

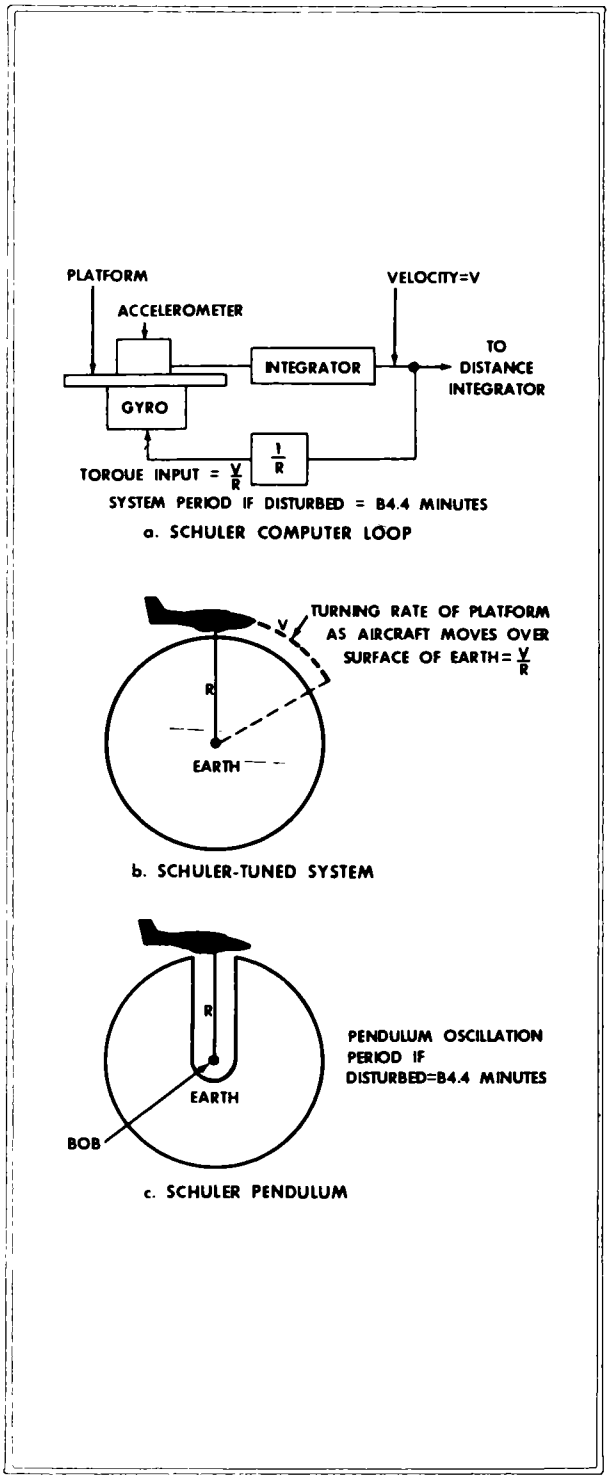


Figure 17-9. Principle of Schuler pendulum.

b. The torquing rate necessary to maintain the platform level with respect to the surface of the Earth is dependent on vehicle velocity. The rate is the aircraft velocity divided by the radius of the Earth (fig 17-9). The system is mechanized so that the velocity is multiplied by the reciprocal of Earth's radius and the resulting signal is sent to the gyro torquer to produce the proper platform torquing rate.

c. The operation of the inertial platform when mechanized in this way is very much like a string pendulum having a radius equal to Earth's radius or approximately 3,440 miles. In effect, the pendulum bob's center of gravity (CG) remains at the center of the Earth, allowing the point of suspension (aircraft) to be moved at will. Thus, the platform orientation is able to define the true vertical.

d. If the platform could maintain this true vertical orientation at all times, the job of the system operator would be cut drastically. The accelerometers would sense only true velocity changes, apparent precession corrections would be computed and applied properly, and position would remain exact at all times. This would relieve the operator of his updating procedures and the aircraft would fly directly over the selected destination. The situation mentioned above rarely exists for a pure inertial system that is alined on the ground. Because some platform tilt remains after alinement, the gravity component continues to affect the inertial velocities causing them to again start to go in error. During this time, aircraft position will drive proportionally in error. To maintain the platform to a local level, the gyros are torqued by computed Earth rate and transport corrections. However, with erroneous inertial velocities, the platform will be torqued in error. Figure 17-10 shows how the platform and its computed velocities will oscillate rather than maintain the existing errors.

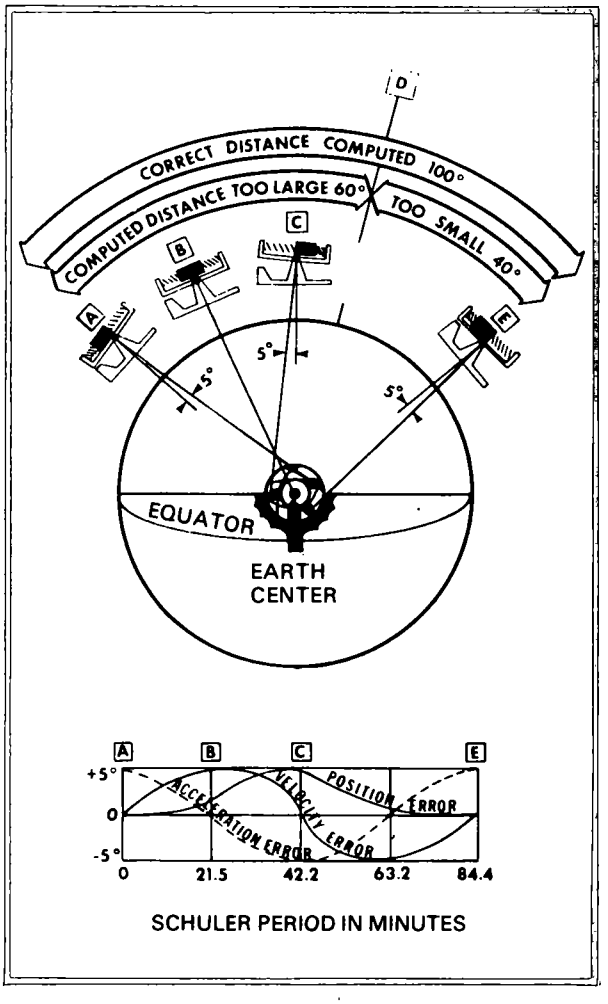


Figure 17-10. Schuler-tuned platform oscillations.

e. Position A shows the platform at the end of gyrocompass alinement with 5° of tilt remaining. The gravitational forces on the accelerometer cause the inertial velocity along the east axis to erroneously increase (assuming the direction of flight to be along the east axis). At a given time later, the stable platform will compute an angular distance traveled of 60°. However, in reality, the stable platform has traveled an angular distance of 50° to point C. By applying its computed correction of 60°, the stable platform has overcorrected itself by 10°. It is now 5° out of level, but in the other direction. This new tilt allows gravity to be sensed as a deceleration and velocity east erroneously decreases. At an equal time later, the stable platform has again (1) actually traveled 50° and is at point E; (2) due to its sensed deceleration, computed distance traveled as 40° which is also its actual position at that time; and (3) overcorrected itself by 10° and is in its original tilt configuration. This period of oscillation which is inherent to inertial systems is called the Schuler period and recurs every 84.4 minutes.

17-9. CORIOLIS EFFECT AND EARTH OBLATENESS

Given such a workably stabilized platform, it is now possible to accurately measure accelerations. These measurements, however, include two forces not as yet accounted for—*Coriolis* and *the effect of the oblateness (flatness) of the Earth.*

a. *Coriolis.* Coriolis is a deflecting force exerted by a rotating base (the Earth) on any object moving over this base. To understand this force, imagine yourself at the center of a large rotating disk, trying to reach a point at the rim of this disk (fig 17-11). Imagine further, that the disk is segmented so that you have to jump from one segment to the next. You cannot reach your aim point at the rim in a straight line because each segment ahead of you travels at a faster speed than the one on which you are standing. You can, of course, maintain a seemingly straight line by carefully leading each aim point at each jump; but if you plot your actual course, you will have approached your goal in a curve, which causes airplanes or missiles to be deflected to the right of direction in the northern hemisphere and to the left in the southern

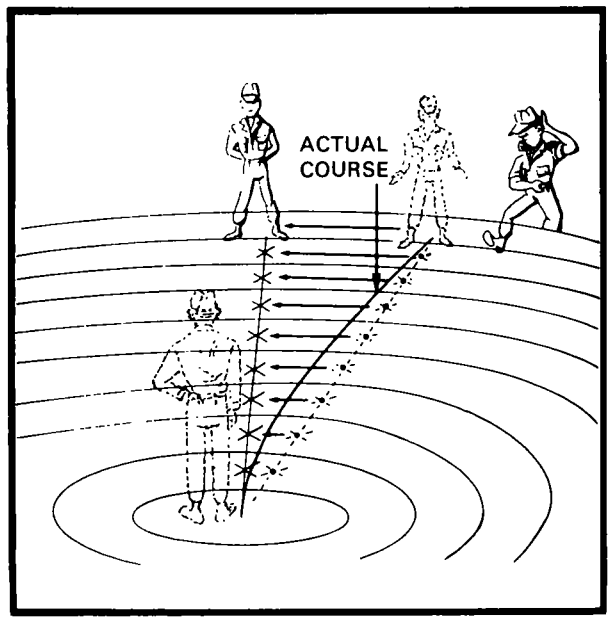


Figure 17-11. Coriolis spoils straightforward intentions.

hemisphere. To cancel the effect of the Coriolis force, a correction signal is generated equal to and opposite of the Coriolis term, which is summed with the acceleration signal (fig 17-12).

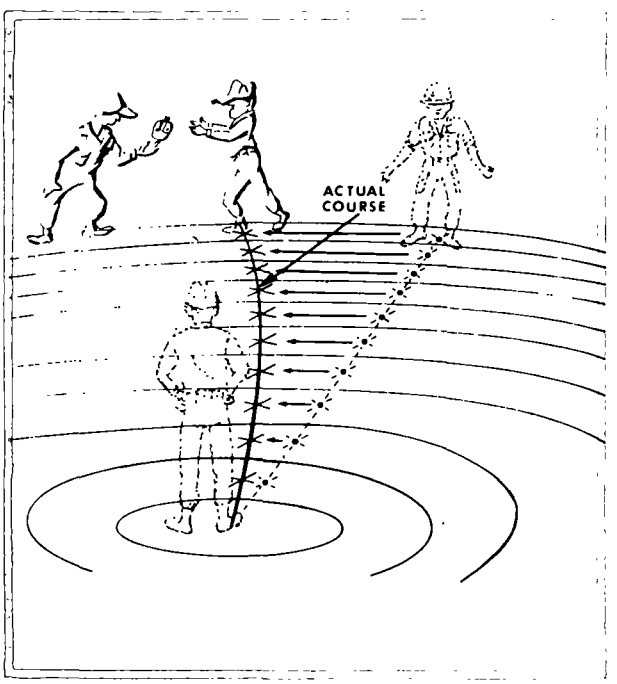


Figure 17-12. Devious (Coriolis corrected) aim gets results.

b. *Effect of the Oblateness of the Earth.* This causes a phantom acceleration in certain latitudes where the plumb line to the center of the Earth does not exactly coincide with the true vertical (fig 17-13). The resulting platform imbalance causes a spurious acceleration indication for which the digital computer provides exact correction terms by adjusting "R" in the V/R torquing formula.

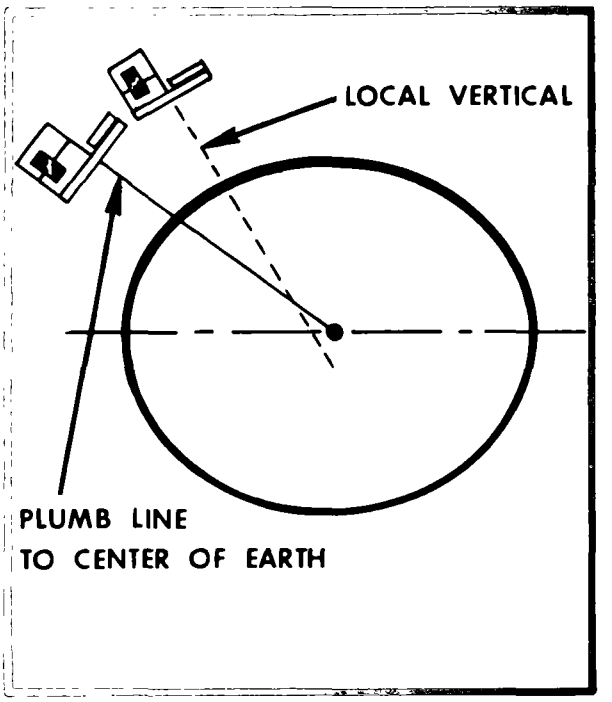


Figure 17-13. Oblate spheroid.

17-10. RECAPITULATION OF INERTIAL NAVIGATION

a. Inertial navigation may be described as follows. Accelerometers, mounted on a stable element at right angles to each other, measure accelerations (or decelerations) of the aircraft along their respective sensitive axis. These measurements represent local accelerations containing components of aircraft acceleration, as well as torque rate. They also include phantom accelerations due to Coriolis force and the oblateness of the Earth.

b. By removing the unwanted components and integrating the remaining acceleration, the computer obtains linear

velocities. It uses these velocities to develop the gyro torquing currents which close the feedback loop by maintaining the platform level and pointing to true north. In computing the torques, the computer uses trigonometric functions wherein each of the level axes is represented by the radius of the Earth; this causes the platform to behave as a Schuler pendulum having an 84-minute period during which errors due to misleveling are time-averaged to zero. The computer integrates linear velocities a second time to obtain distance traveled from the point of origin. This computation determines present position. Attitude is monitored continuously by pickoff devices measuring the displacement of the gimbals.

17-11. SYSTEM ALINEMENT

a. The first step necessary in the operation of an inertial guidance system is to have the stable element level with respect to the local vertical and accurately alined with respect to north.

b. The precise leveling of the platform is accomplished by making use of the accelerometers which measure any tilt of the platform. The platform is driven until the accelerometer outputs are zero, thus indicating that the accelerometers are not measuring any components of gravity and that the platform is level. During this time, aircraft movement will result in misalinement and should be avoided.

c. Coarse azimuth alinement of the stable element is accomplished by using the magnetic compass transmitter (flux valve) in the aircraft as a reference and driving the stable element to north as indicated by the remote magnetic compass transmitter (plus handset magnetic variation). However, the azimuth accuracy obtained in this way is not sufficient for precise inertial navigation, so a self-azimuth-alinement by gyrocompassing is used to complete the alinement process.

d. Gyrocompassing makes use of the ability of the accelerometers to sense the rotation of the Earth. If the platform is misalined with respect to north, the rotation of the stable element produced by the Earth rate torquing will not be in step with the rotation of the Earth, and the platform will start to tip along the sensitive axis of the accelerometer which measures north-south acceleration. Self-alinement by gyrocompassing is accomplished by feeding the output of this accelerometer to the torquer of the azimuth gyro, thereby causing the stable element to move in azimuth until the accelerometer is alined with respect to north. The platform is maintained in a leveling mode while this gyrocompass alinement takes place.

Section III. THE OPERATION OF THE AN/ASN-86 INERTIAL NAVIGATION SET

17-12. FUNCTIONS

a. The AN/ASN-86 inertial navigation set (fig 17-14) is an aircraft navigation and attitude reference system that will operate totally independent of maneuvers, weather conditions, and terrain. It does not radiate or receive radiations; it is impervious to countermeasures; and input data is

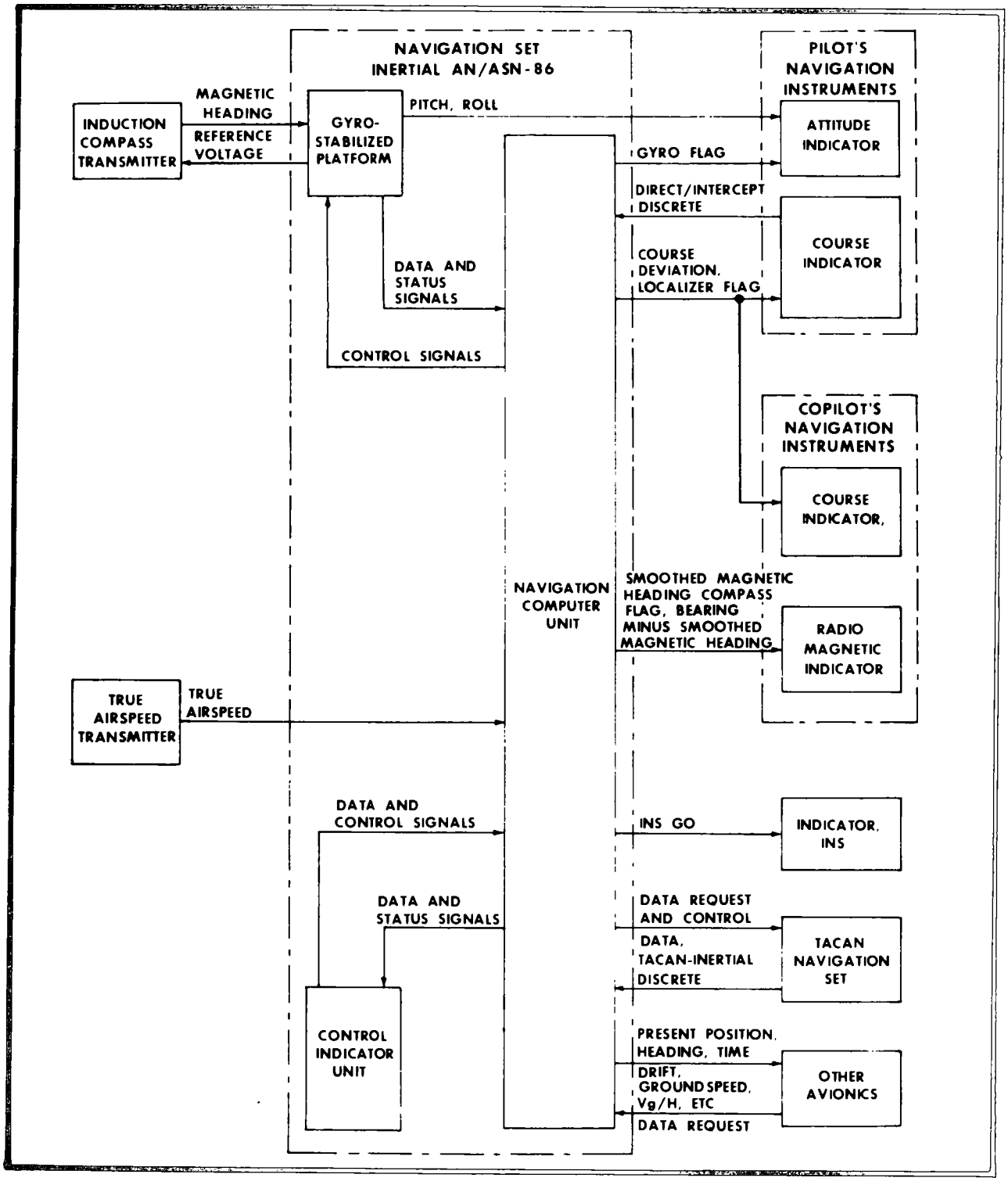


Figure 17-14. A typical block diagram for inertial navigation set AN/ASN-86.

required solely for initiating or correcting navigational references in the computer. This equipment will support all-weather tactical operations with a continuous display of navigational information selected to accomplish the mission. A total of 20 destinations can be inserted into the set at one time, 10 of which can be tactical air navigation (TACAN) stations for use in automated updating.

b. The navigation set provides the following visual displays:

(1) Bearing to selected destinations and TACAN stations.

(2) Range to selected destinations and TACAN stations.

(3) Present position in universal transverse mercator (grid) (UTM) coordinates.

(4) UTM coordinates of the selected destination or TACAN station.

(5) Latitude and longitude (lat/long) coordinates of present position.

(6) Latitude and longitude coordinates of selected destination or TACAN station.

(7) Calculated present position magnetic variation or inserted TACAN station local magnetic variation.

(8) Course select angle manually inserted for intercepting a destination or TACAN station on a desired inbound track.

(9) Altitude of selected TACAN station.

(10) Channel number of selected TACAN station.

(11) Display of distances in kilometers east-west and north-south between the computed present position of the aircraft and the coordinates of the selected destination or TACAN station (for evaluation (eval) of ASN-86 accuracy at the time of a position fix).

(12) Wind direction and windspeed.

(13) Ground track angle.

(14) Groundspeed.

(15) True heading.

(16) Flight time to selected destination or TACAN station.

(17) Actual operating time in each mode (MON 5).

(18) Readout of any preselected computer core storage location.

c. In addition to the readout of data on the control indicator unit panel of the AN/ASN-86, selected data can be output to the aircraft instrument panel or to ancillary aircraft equipment. For example, course deviation signals, smoothed magnetic heading, and bearing-minus-heading information can be routed to the course director and radio magnetic indicators. Outputs of aircraft position, time, heading, and speed can be furnished to maintain orientation of other airborne recording or data collection equipment.

[redacted]

a. In initiating the alinement and operation of the set, three inputs are required. The first two of these, the local magnetic variation and the aircraft present position (either in UTM or lat/long coordinates) are manually inserted by the operator and must be known as accurately as possible. The third input is the magnetic aircraft heading from the magnetic compass transmitter. The combined input from these provides the coarse alinement of the platform to true north and the subsequent position from which fine alinement is made during gyrocompassing. The latitude of the present position should be as accurate as possible (600 feet or 0.2 kilometers (km) or 0.1 nautical mile (NM)). If the magnetic variation is not precisely known, or if local magnetic influences cause deviations in the magnetic compass output, then the operator can insert a value for magnetic variation that causes the true heading readout on the indicator to agree with actual aircraft true heading on the ramp. These heading values should be known to one and one-half degrees of accuracy or better.

b. When the system is operating in the navigate mode using inertially derived data, the difference between the aircraft true heading and the magnetic compass heading is calculated as local magnetic variation and can be read directly on the indicator.

c. The magnetic variation is set by hand during the setting of TACAN station information.

d. TACAN data can automatically be used by the computer to update the inertial position. This TACAN update is the automatic counterpart of the manual position update that can be accomplished by the pilot or copilot. The mechanization of the automatic TACAN update, however, will insure an accuracy of update that is unattainable by an operator. If this automatic input were to fail, the equipment can be manually updated in reference to any accurate ground position. True airspeed data is supplied by the true airspeed transducer which the computer uses to calculate wind in the inertial mode and to perform dead-reckoning navigation in the air data mode.

[redacted]

a. The gyro-stabilized platform is a complete inertial navigation measuring unit. It contains an all-attitude, four-gimbaled stable element with necessary electronic circuits and control components.

b. The stable element is the basic reference center for the system. It is located within the azimuth gimbal in the heart of the assembly. It mounts two precision gyroscopes and extremely sensitive accelerometers. The gyros are located one above the other with the spin axis of both designed to operate in the horizontal plane, but with the upper gyro Y-axis alined north and the lower gyro X-axis alined east. The sensitive axis of an accelerometer is alined with each of these axes. Their outputs provide all of the inertial measurements required to aline the system and navigate with it.

c. In normal operation, the precision gyroscopes sense any tendency for the stable element to move from the established orientation in the vertical and horizontal plane. The roll, pitch, and azimuth gimbal loops with their servo drives are keyed to a related gyro pickoff coil. Any relative motion between the gyro and its mount generates a signal in the appropriate gimbal servo loop, and the stable element is commanded to the gyro orientation. In this manner, the gimbal assemblies, with their associated electronics, effectively isolate the stable element from any disturbing external motion.

d. In addition, gyro torquing signals are calculated within the computer that are scaled to compensate for the effects of the rotation of the Earth and the movement of the aircraft over it. These corrections cause the gyros, and hence the entire stable element, to maintain a true north azimuth; the accelerometers are held perfectly level. In this condition, their outputs, integrated into incremental velocity components in the north-south and east-west directions, provide the basis for inertial navigation calculations. Aircraft altitude and true heading are measured as angles between the associated roll, pitch, or azimuth gimbal and the stable element. All this data can be output to the computer or processed for readout in the control indicator panel or other remote aircraft instruments.

17-15. THE NAVIGATION COMPUTER

a. All incremental and whole number computations required in the operation of the ASN-86 inertial navigation set are handled within the navigation computer. This unit is a solid-state, general-purpose, digital computer. It has a 4,096-word magnetic core memory for 28 bit data, address, and instruction words. It also contains input/output section, an arithmetic section, and a command section that interact to accept external data, communicate and execute program operations internally, and provide resolved digital and analog data as outputs.

b. The tactical program that controls the computer operation is inserted by maintenance personnel on the ground. Once stored in the memory, it cannot be altered in flight. However, certain navigational information, such as present position magnetic variation, aircraft altitude, and locations of selected destinations or TACAN sites, must be inserted by the operator to augment the computer program. These values must be entered to enable proper system operation. Externally derived windspeed and direction must be entered in air data (AD) mode for dead-reckoning (DR) operations.

c. Where automatic TACAN fix information is available, the operator can also switch in TACAN positional data and the inertial position within the computer can be automatically updated to agree. Of course, either manual or automatic insertion of any erroneous values can contribute to erroneous computations that will give rise to incorrect readouts and improper control signals to the inertial platform. The operator must use care and be certain that the input data is accurate or the entry must be withheld.

[redacted]

a. The control indicator unit serves as the interface between the operator and the inertial navigation set. Rotary controls, the keyboard, and command pushbuttons provide for the entry of preplanned flight data and subsequent in-flight changes that may be required. Indicator lights, alpha-numeric displays, and the switch positions will provide identified readouts of the data that has either been entered by the operator or established by the computer from inertially derived navigation information (fig 17-15 and 17-16).

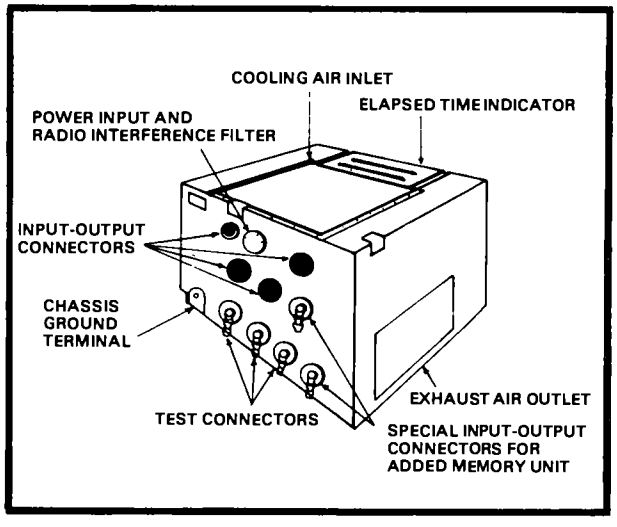


Figure 17-15. Computer.

b. Damage to the system cannot be caused by any combination of control settings or pushbutton sequencing. If, however, the CONTROL INDICATOR MODE switch (fig 17-16) is moved from the NAV position during flight, the inertial navigation capability is disabled. The set can then be operated in the air data mode. If it is obviously malfunctioning, it must be turned off and realined later on the ground.

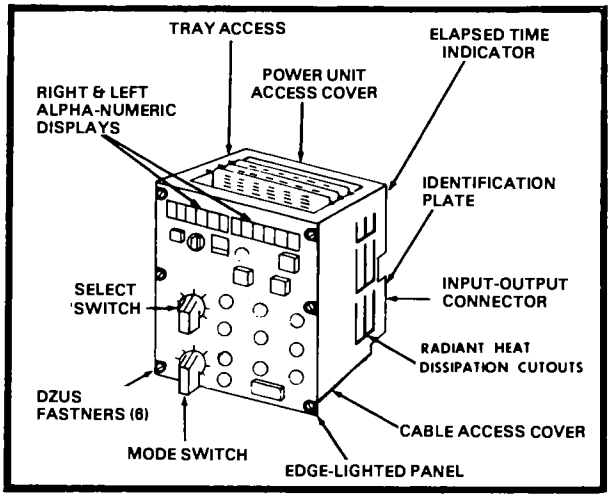


Figure 17-16. Control/indicator unit.

[redacted]

a. The front panel of the control/indicator unit contains all switches and indicators needed by the aircrew to actuate the set, insert initial reference data, select the operating mode, and read out the desired navigational or performance information (fig 17-17).

b. Prior to operating the set, the aircrewmember should—

(1) Be familiar with the operating controls and displays on the control/indicator panel.

(2) Be ready to insert precise values for aircraft present position on the

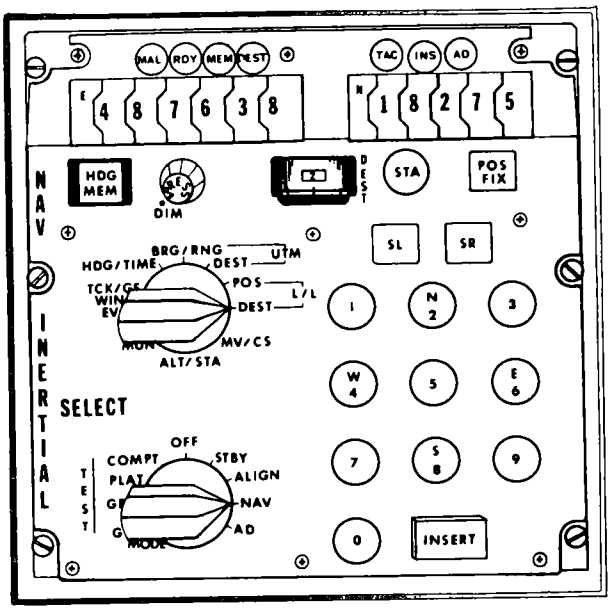


Figure 17-17. The control/indicator unit (face).

ramp and the exact local variation unless heading memory has been established.

(3) Have a handy list of data pertaining to the destinations and the TACAN stations that he intends to use.

(4) Make certain preliminary checks of power and control settings before initiating turn-on sequences.

(5) Allow sufficient time to warm up and ground aline the platform to attain optimum navigational accuracy.

17-18 SWITCHES AND INDICATORS

a. *Features of the CIU.* Features of the CIU are listed in (1) through (10) below. The function of the control or details of the indicator will be explained in the same order as listed.

(1) Mode switch.

(2) Select switch.

(3) Station selection pushbutton.

(4) Destination entry thumbwheel.

(5) Coordinate directional indicators.

(6) Data display.

(7) Data entry switches.

(8) Position fix pushbutton.

(9) Lights and indicators.

(10) Heading memory switch.

b. *Mode Switch* (fig 17-18).

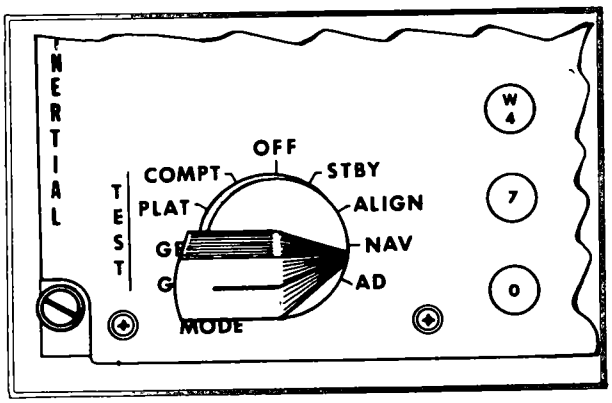


Figure 17-18. Mode switch.

(1) OFF. Turns navigation set off.

(2) STBY. Initiates standby mode of operation. In this mode, primary power

is applied to the computer and control indicator, and heater power is applied to the platform.

(3) ALIGN. Initiates aline mode of operation. In this mode, the platform stable element is leveled with respect to the local vertical and alined to true north.

(4) NAV. Initiates navigate mode of operation. This is the normal mode selected for flight.

(5) AD. Initiates air data mode of operation. This mode is automatically selected if the platform malfunctions during the navigate mode of operation. The air data mode may be selected manually as an alternate to the navigate mode.

(6) Test positions of mode switch. Switch positions to the left of OFF are used on the ground normally by maintenance personnel to test the computer or the platform or to determine gyro-bias values.

> *CAUTION:* **Do not turn on these positions in flight because alinement of the set will be lost.**

c. *Select Switch (fig 17-19).*

(1) MON. Permits readout (left and right displays) of selected performance data.

(2) EVAL. Permits position fix updating and readout (left and right displays) of the N-S and E-W difference

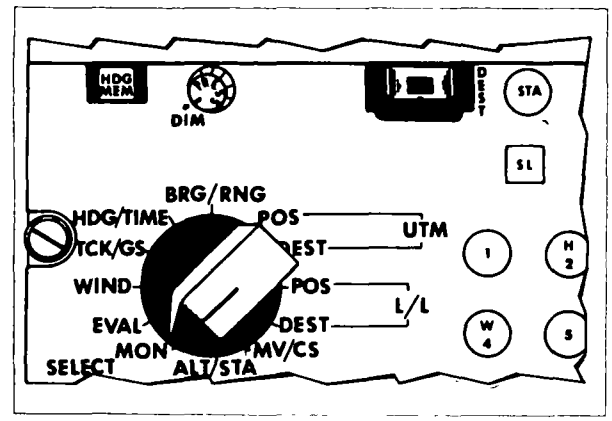


Figure 17-19. Select switch.

between present position and the destination selected by the DEST thumbwheel switch after the POS FIX pushbutton is depressed. In order to accomplish a manual position update, the SELECT switch must be placed in EVAL before depressing INSERT. The differences displayed show the error between position inserted in the thumbwheel location and the computed position of the aircraft at the instant POS FIX was depressed.

(3) WIND. With the MODE switch set to NAV, permits readout (left display) of wind direction with respect to true north and readout (right display) of windspeed. With the MODE switch set to AD, permits insertion and readout (left display) of windspeed.

(4) TCK/GS. Permits readout (left display) of the ground track angle with respect to true north and readout (right display) of groundspeed.

(5) HDG/TIME. Permits readout (left display) of aircraft heading with respect to true north and readout (right display) of time to the destination or TACAN station selected by DEST thumbwheel switch and STA pushbutton switch-indicator.

(6) BRG/RNG. Permits readout (left display) of bearing to the destination or TACAN station selected by the DEST thumbwheel switch and STA pushbutton switch-indicator and readout (right display) of range to the destination or TACAN station selected. Also used in conjunction with DEST thumbwheel switch, STA and INSERT pushbutton switch-indicators to select the destination or TACAN station for navigation set control of aircraft navigation instruments.

(7) UTM POS. Permits insertion or readout (left display) of zone numbers and easting distance and insertion or readout (right display) of northing or southing distance.

(8) UTM DEST. Permits insertion or readout (left display) of zone number and easting distance and insertion or readout (right display) of northing or southing distance of the destination or TACAN station selected by the DEST thumbwheel switch and STA pushbutton switch-indicator.

(9) L/L POS. Permits insertion or readout (left display) of present position longitude and insertion or readout (right display) of latitude.

(10) L/L DEST. Permits insertion or readout (left display) of longitude and insertion or readout (right display) of latitude of the destination or TACAN station selected by the DEST thumbwheel switch and STA pushbutton switch-indicator.

(11) MV/CS. With the STA pushbutton switch-indicator "OUT" (indicator light "OFF"), permits insertion or readout (left display) of present position magnetic variation and insertion or readout (right display) of the course select angle through the destination selected by DEST thumbwheel switch. With the STA pushbutton switch-indicator "IN" (indicator light "ON"), permits insertions or readout (left display) of the local magnetic variation of the TACAN station selected by DEST thumbwheel switch and insertion or readout (right display) of the course select angle through the TACAN station selected.

(12) ALT/STA. With the STA pushbutton switch indicator "OUT" (or indicator light "OFF"), permits insertion or required aircraft altitude above sea level (ASL) for use in automatic TACAN update. Last values inserted are read out directly. With the STA switch-indicator "IN" (indicator light "ON"), permits insertion or readout (left display) of altitude above sea level of the TACAN tower selected by the thumbwheel switch and insertion or readout (right display) of the selected TACAN station channel number.

Note. **In aircraft where TACAN updating is not programed, the right display may hold radar altitude and left display will be blank.**

d. *Station Selection Pushbutton.* STA is used in conjunction with DEST thumbwheel switch to select destinations or TACAN stations. It lights when a TACAN station is selected (fig 17-20).

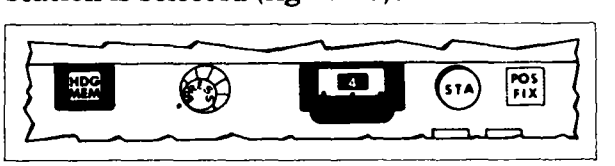


Figure 17-20. Station selection pushbutton.

e. *Destination Entry Thumbwheel* (fig 17-21). The destination entry thumbwheel permits the insertion or readout of data determined by the SELECT switch position. With STA switch "OUT," the action pertains to the numbered destinations selected; with STA switch "IN," the action pertains to the data entered into the 10 positions set up for TACAN. If coordinates only are entered, these positions serve as added destinations. If, however, actual coordinates of TACAN stations are entered (along with station altitude, magnetic variation, and station number), the data can be used for automatic TACAN updating.

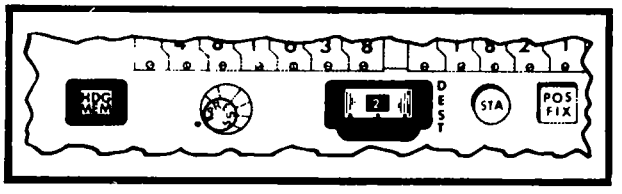


Figure 17-21. Destination entry thumbwheel.

f. *Coordinate Directional Indicators* (fig 17-22).

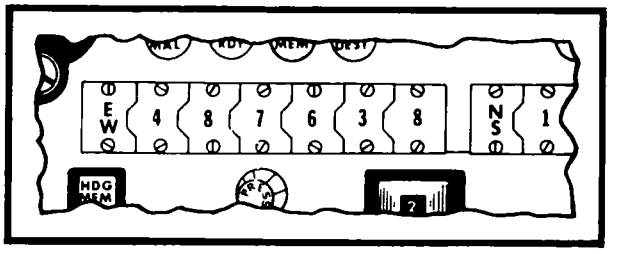


Figure 17-22. Coordinate directional indicators.

(1) E/W. Indicates the direction, east or west, of the data displayed on the control indicator.

(2) N/S. Indicates the direction, north or south, of the data displayed on the control indicator.

g. *Data Display* (table 17-1).

Table 17-1. Data Display

Select Switch	Maximum value of variable—left display	Units of variable left display	Maximum value of variable—right display	Units of variable rights display
BRG/RNG	0359.9	Degrees	9999.9	Kilometers
UTM POS	60:999.9	Kilometers	9999.9	Kilometers
L/L POS	E/W 179°59.9	Degrees & Minutes	N/S 89°59.9	Degrees & Minutes
L/L DEST	E/W 179°59.9	Degrees & Minutes	N/S 89°59.9	Degrees & Minutes
MV/CS	E/W 00179.9	Degrees	359.9	Degrees
ALT/STA	00099.9	FT(1000 s)	00126	Station number
MON	N/S 9999.9		N/S 9999.9	
EVAL	N/S 9999.9	Kilometers	N/S 9999.9	Kilometers
WIND	00359.9	Degrees	0600.0	Knots
TCK/GS	00359.9	Degrees	0600.0	Knots
HDG/TIME	00359.9	Degrees	9999.9	Minutes

h. *Data Entry Switches* (fig 17-23).

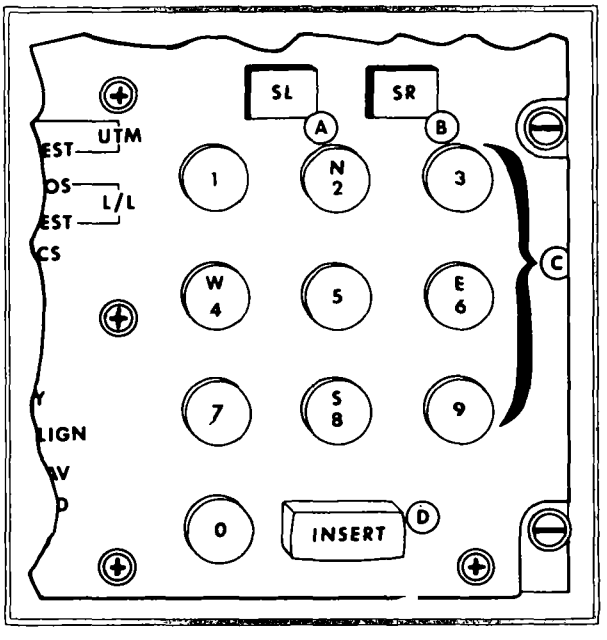


Figure 17-23. Data entry switches.

(1) SL. When pressed, clears left display and INSERT indicator lights.

(2) SR. When pressed, clears right display and INSERT indicator lights.

(3) KEYBOARD (C). Keys are pressed in conjunction with the SELECT switch, DEST TW switch, SL, SR, switch-indicators, to load left and right displays. The direction is specified first by pressing the N/2, E/6, S/8, or W/4 pushbutton to insert the appropriate numerical data.

(4) INSERT. Pressed to enter original information update data in the computer.

i. *Position Fix Pushbutton* (fig 17-24). The POS FIX, when pressed, establishes the instant at which the position fix error is to be computed and stored. With the SELECT switch set to EVAL, UTM POS, or L/L POS, the left and right displays are frozen when the POS FIX switch indicator light is on.

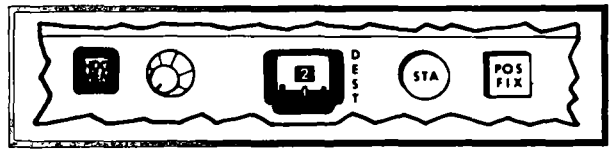


Figure 17-24. Position fix pushbutton.

j. *Lights and Indicators* (fig 17-25).

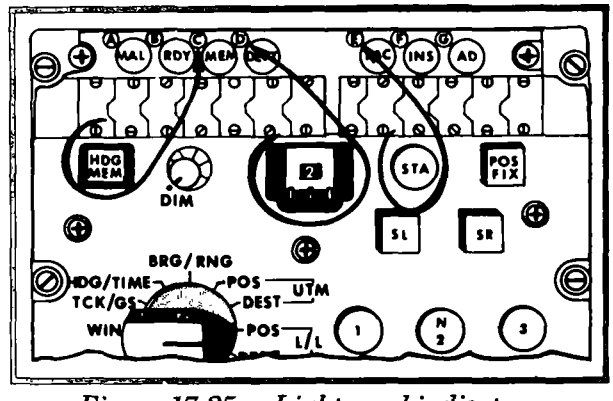


Figure 17-25. Lights and indicators.

(1) MAL. Lights when the navigation set malfunctions.

(2) RDY. Flashes when set is ready for navigate mode.

(3) MEM. Lights when heading memory alinement is in progress or previously set up for such alinement.

(4) DEST. Lights when aircraft is within 2 minutes flying time of destination. Flashes when destination is passed or the range to the selected destination begins to increase.

(5) TAC. Lights when navigation set is using TACAN data for automatic updating of present position.

(6) INS. Lights when navigation set is operating in the inertial or NAV mode.

(7) AD. Lights when the navigation set is in the air data mode of operation.

k. *Heading Memory Switch* (fig 17-26). The HDG MEM, when pressed any time after completion of alinement and held in (until MEM indicator lights come on), permits heading memory alinement on the subsequent navigation set turn on.

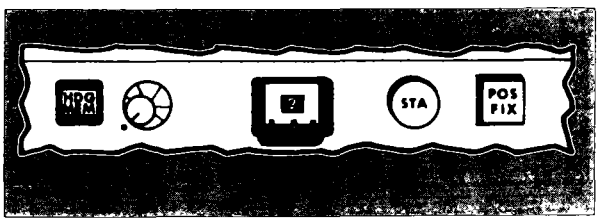
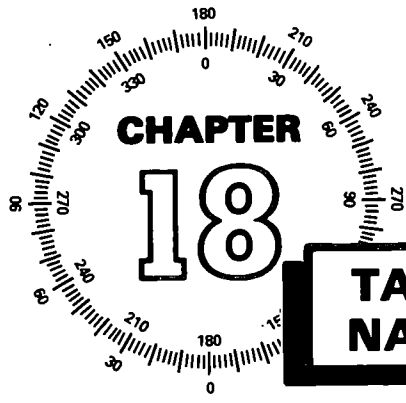


Figure 17-26. Heading memory switch.



CHAPTER 18

TACTICAL AIR NAVIGATION (TACAN)

18-1. INTRODUCTION

Although VHF omnidirectional range (VOR) was a great improvement over earlier navigational systems, a gap still existed in the navigational information available to the aviator. The tactical air navigation (TACAN) system was developed to fill this gap by providing the aviator with information needed for precise geographical fixing of the position of his aircraft at all times. In addition to the displayed bearing information, TACAN adds a continuous display of range information. Like VOR, TACAN provides 360 courses radiating from a station. Distance measuring equipment (DME), an integral part of TACAN, provides continuous slant-range distance information. An additional advantage is that TACAN ground equipment is compact and relatively easy to transport, thus providing for great versatility in beacon installation and mobility. Stations that have VOR and TACAN systems collocated are called *VORTAC* stations.

18-2. FREQUENCIES AND EQUIPMENT

a. *Frequencies.* TACAN operates in the ultra high frequency (UHF) (1,000 megahertz (MHz)) band with a total of 126

two-way channels in the operational mode (X or Y). The DME air-to-ground frequencies for these channels are in the 1,025 to 1,150 MHz range and the associated ground-to-air frequencies are in the 962 to 1,213 MHz range.

b. *Ground Equipment.* TACAN ground equipment consists of a rotating type antenna for transmitting bearing information and a receiver-transmitter (transponder) for transmitting distance information. The TACAN station is identified by an international Morse coded tone modulated at 1350 hertz (Hz) with a reception interval of approximately 30 seconds.

Permanent TACAN ground stations are usually dual transmitter equipped (one operating and one on standby), fully monitored installations which automatically switch to the standby transmitter when a malfunction occurs. The ground monitor (set to alarm at any radial shift of plus or minus 1°) is usually located in the base control tower or approach control and sets off a light and buzzer to warn the ground crew when an out-of-tolerance condition exists. Anytime TACAN reception is suspected of being in error or bearing/distance unlock conditions are encountered in flight, an aviator can check on the status of the ground equipment by calling air traffic control (ATC). When ground equipment is undergoing tests or repairs which might cause it to transmit erroneous signals, its identification is silenced; therefore, the aviator should listen for identification signals during flight.

[illegible] PATTERNS

The signal pattern for bearing information is formed by varying the nondirectional pattern sent from the stationary central element of the TACAN transmitter antenna (fig 18-1). The two types of bearing signal patterns are the *coarse azimuth pattern* and the *fine azimuth pattern.*

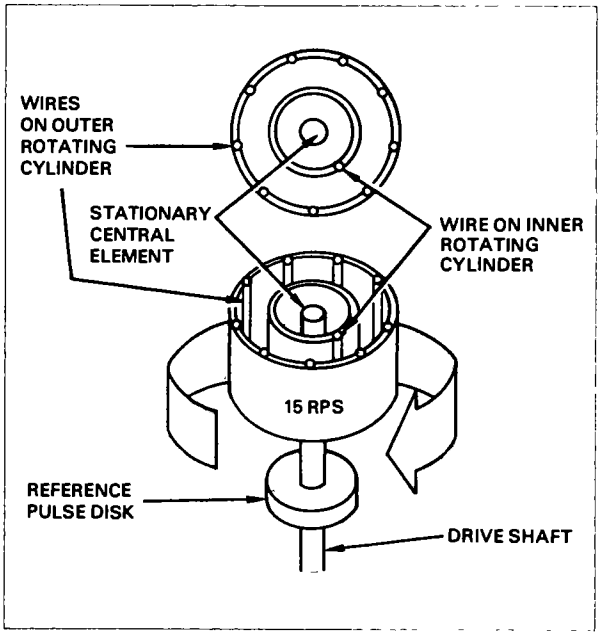


Figure 18-1. TACAN ground beacon antenna design (azimuth).

a. *Coarse Azimuth Pattern.* This pattern is created by rotating a plastic cylinder around the central element of the antenna at 15 revolutions per second (rps). A metal wire embedded vertically in the cylinder distorts the radiated signal into a cardioid (heart-shaped) pattern, and its rotation causes the cardioid pattern to also revolve

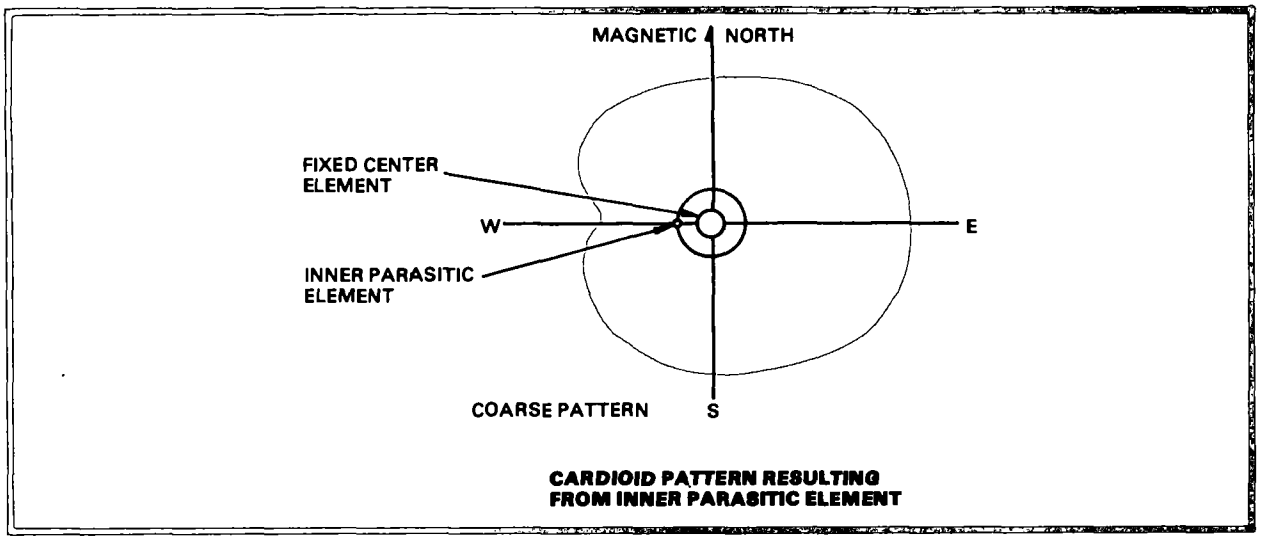


Figure 18-2. Coarse azimuth pattern.

at 15 rps. This resulting rotating pattern (fig 18-2) is referred to as the *coarse pattern*. From this, the aircraft receives an amplitude modulation of 15 Hz. This means that the strength of the signal goes from maximum to minimum and back to maximum at the rate of 15 times per second.

b. *Fine Azimuth Pattern.* To produce the fine pattern, another larger plastic cylinder containing nine wires is mounted around the central element and the smaller cylinder, and also rotates at 15 rps. This is the *fine* antenna which superimposes nine lobes on the already formed coarse pattern (fig 18-3). This forms a 135-Hz signal.

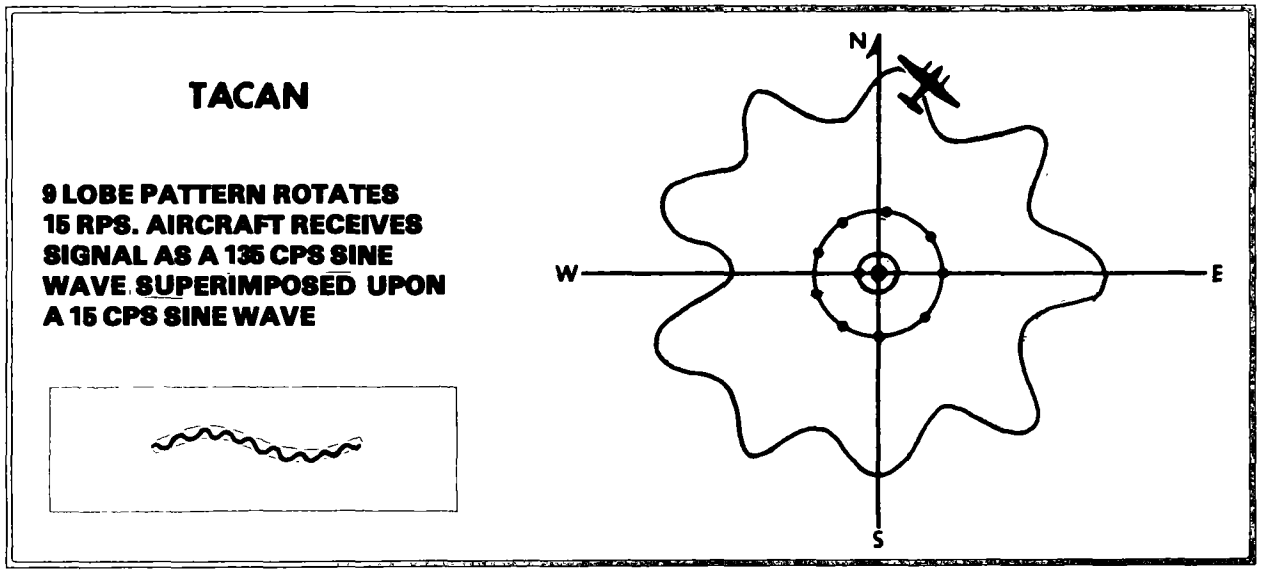


Figure 18-3. Fine azimuth pattern.

c. *Bearing Determination.* To determine the aircraft's bearing from the station, a phase angle must be electronically measured. To measure the phase angle, a fixed reference is established. This fixed reference is a 15-pulse-per-second (pps) nondirectional signal normally referred to as the main reference bearing pulse. One main reference pulse occurs with each revolution of the antenna when the peak of the cardioid is at a magnetic direction of 090°. In addition to the main reference pulse, eight auxiliary reference pulses also occur during one revolution of the ground beacon antenna. Therefore, a reference pulse occurs each 40° of antenna rotation (360° ÷ 9 pulses). The airborne equipment electronically measures the time lapse between the main reference pulse and the maximum amplitude (signal strength) of the 15-Hz rotating signal pattern (fig 18-4). This determines the aircraft's bearing from the station within a 40-degree sector. Then, the time lapse between the auxiliary reference pulses and the maximum amplitude of the 135-Hz signal is measured to determine the aircraft's position within the 40-degree sector. The accuracy of this measurement determines the position of the aircraft relative to the station within plus or minus 1°.

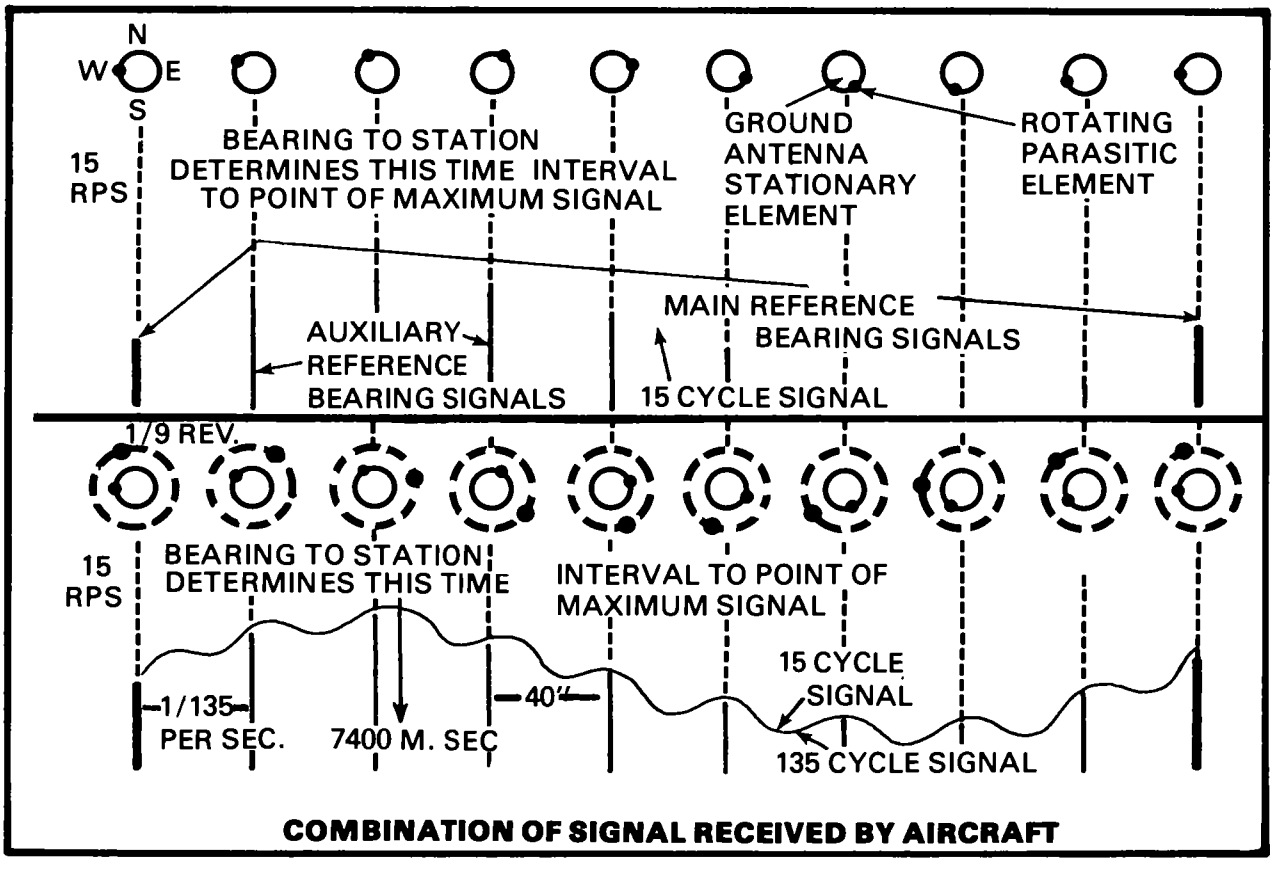


Figure 18-4. Bearing determination.

18-4. DISTANCE MEASURING EQUIPMENT

Distance between the aircraft and the ground station is determined with TACAN equipment by measuring the elapsed time between transmission of interrogating pulses of the airborne set and reception of corresponding reply pulses of the ground station (fig 18-5). The aircraft transmitter starts the process by sending out the distance interrogation pulse signals. Receipt of these signals by the ground station receiver triggers its transmitter which sends out the distance reply pulse signals. These pulses require approximately 12 microseconds round trip travel time per nautical mile (NM) of distance from the ground beacon. The range indicator displays slant-range distance (fig 18-6) to the TACAN beacon in NM. Since a large number of aircraft could be interrogating the same beacon, any particular airborne set must sort out only the pulses which are replies to its own interrogations. Interrogation pulses are transmitted on an irregular, random basis by the airborne set which then "searches" for replies synchronized to its own interrogations. If the signals are interrupted, a memory circuit

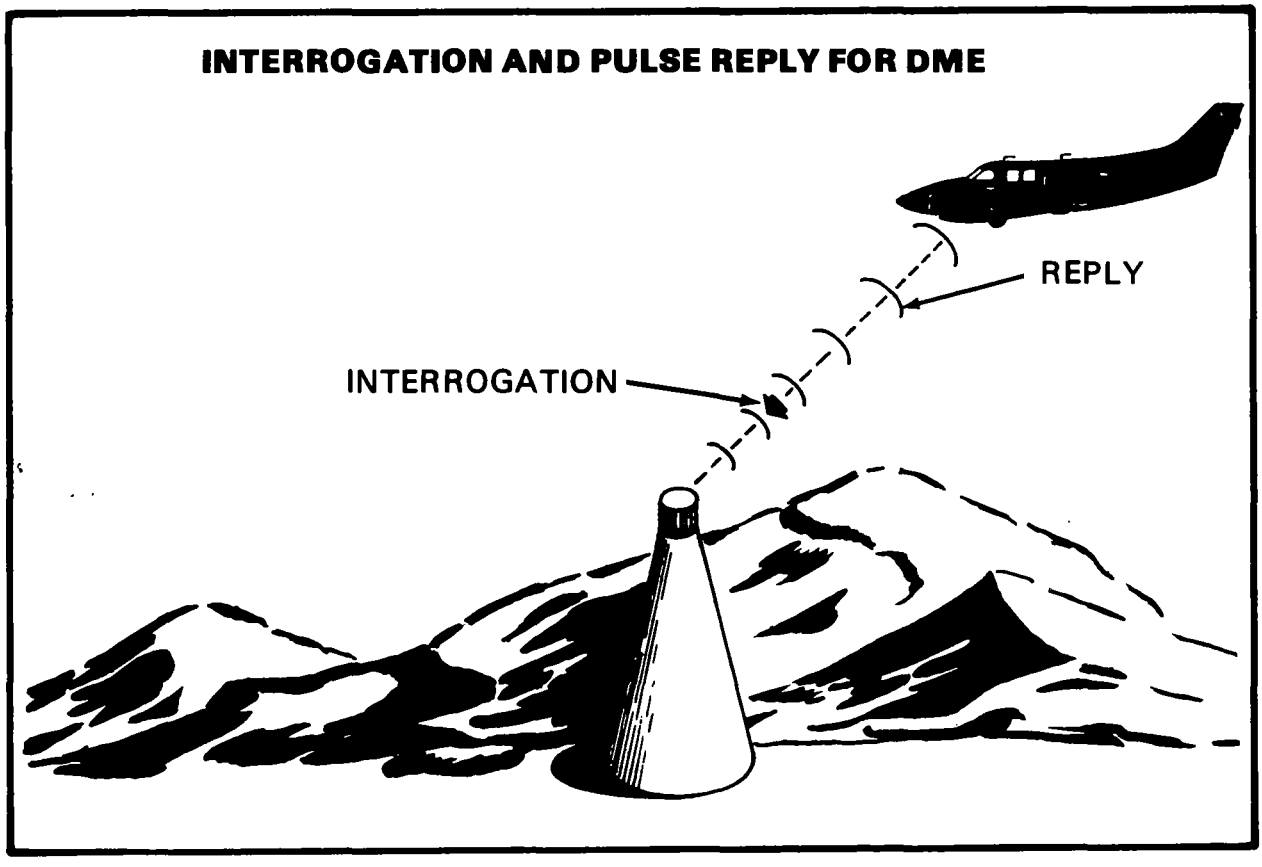


Figure 18-5. DME principles.

maintains the last distance indication on the range indicator for approximately 10 seconds to prevent the search operation from recurring. The searching process starts automatically 10 seconds after the airborne set is tuned to a new beacon or when there is a major interruption in beacon signals. Depending upon the aircraft's actual distance from the beacon at the time, the searching process may require up to 22 seconds.

[redacted]

a. *Bearing/Distance Unlock.* TACAN bearing and distance signals are subject to line-of-sight restrictions because of their utilization of UHF frequencies. Because of the transmission/reception principles, unlock (indicated by rotating of bearing pointer and/or range indicator) will occur if

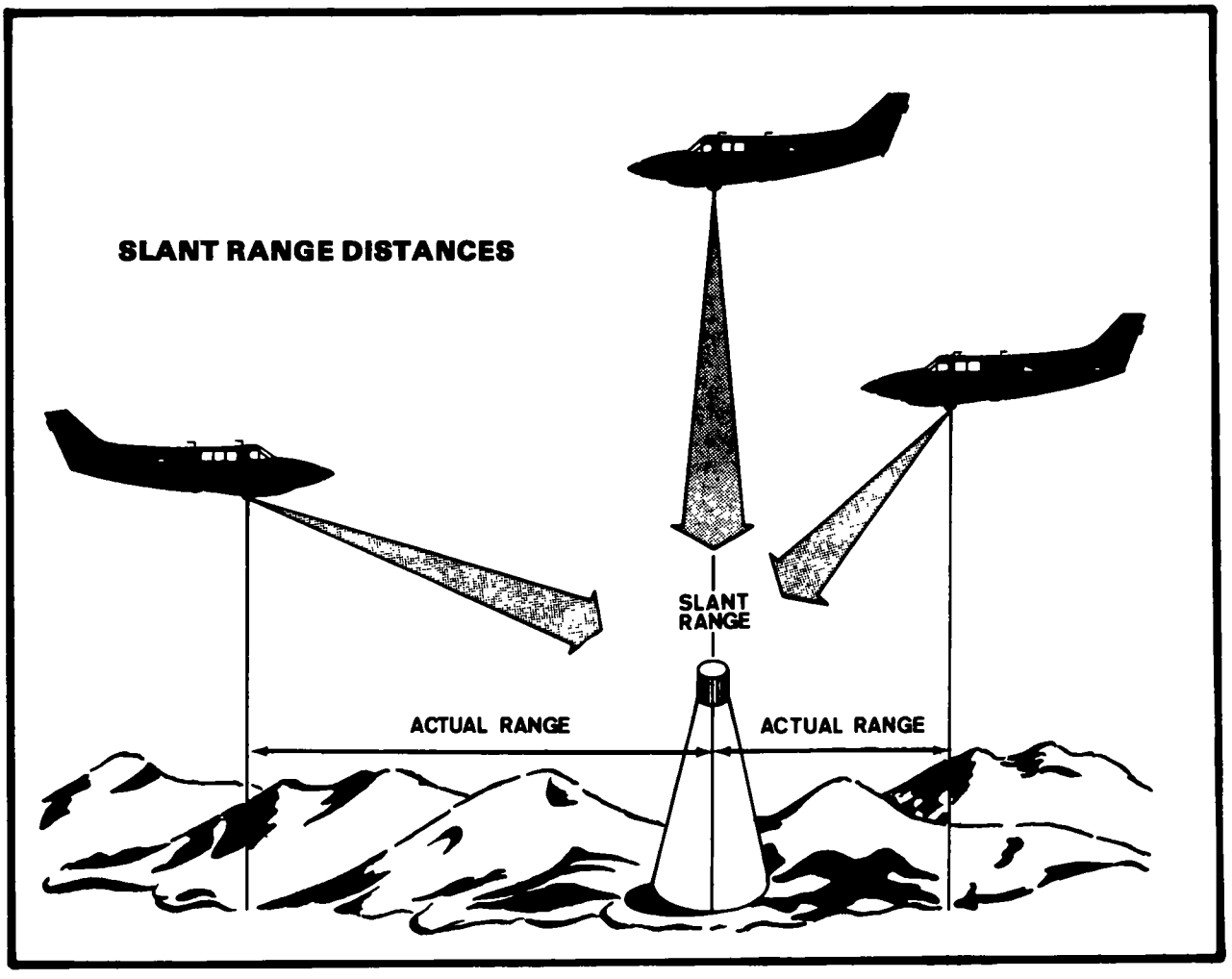


Figure 18-6. DME distances.

these signals are obstructed. Temporary obstruction of TACAN signals can occur in flight when aircraft fuselage, wing, or gear; external stores; or wingmen get between the ground and the aircraft antenna. Aircraft receiver memory circuits prevent unlock for short periods (approximately 10 seconds for DME and 2 seconds for azimuth); but beyond this, unlock occurs and will persist until the obstruction is removed and search cycles are completed. Unlock may occur during maneuvers which cause the aircraft antenna to be obstructed for longer than 2 to 10 seconds; e.g., procedure turns.

b. *Azimuth Cone of Confusion.* The structure of the azimuth cone of confusion over a TACAN station (fig 18-7) is considerably different from other navigational aids (NAVAID). The azimuth cone can be up to 100° or more in width (approximately 15 NM wide at 40,000 feet). Indications on the aircraft instruments make it appear even wider to the pilot. Approaching the TACAN station, usable azimuth information is lost before the actual cone is reached, although actual azimuth unlock is prevented by the memory circuit until after the aircraft has entered the cone. After the cone is crossed and usable signals are regained, the search cycle extends the unusable area beyond the actual cone. Only azimuth information is unusable in the cone of confusion; slant-range distance information continues to be displayed on the range indicator.

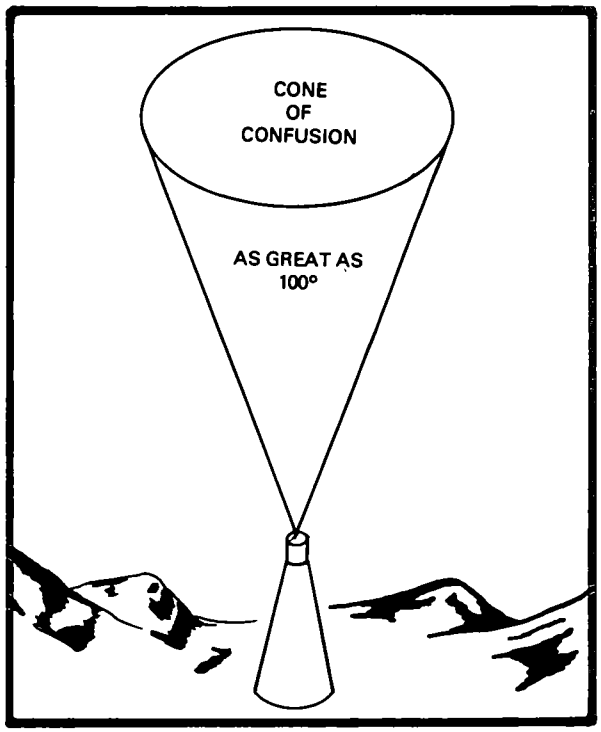


Figure 18-7. TACAN azimuth cone of confusion.

c. *Range Indicator Fluctuations.* Slight oscillations up to approximately one-fourth NM are normal for range indicator operation. When a usable signal is lost, the memory circuit maintains the indicated range for about 10 seconds. If the signal is regained during this period, the indicator will "jump" to the correct reading.

d. *Erroneous TACAN Indications.* Several forms of malfunction of airborne equipment or interference between ground stations can give false or erroneous TACAN navigational information to an aviator. These discrepancies are easier to recognize and guard against if the aviator is aware they can occur. The more common erroneous indications are—

(1) *40° azimuth error lock-on.* The construction of the TACAN ground

antenna is such that it transmits a series of nine signal lobes (eight auxiliary and one main reference pulse) 40° apart. With the airborne receiver working correctly, the main reference pulse (which occurs when the peak of the rotating cardioid pattern is at the 090° magnetic direction) locks on at the 090° slot of the receiver. *With a weak airborne receiver,* the main reference pulse may "slide over" or miss the 090° slot and lock on at one of the auxiliary positions. When this occurs, azimuth indications will be 40° or some multiple of 40° in error. Rechanneling (retuning) the airborne receiver to deliberately cause unlock may cause the receiver to lock on properly. When other bearing information such as VOR or automatic direction finder (ADF) is available, it should be used to verify the position periodically. This type error is unusual (but possible) in present day TACAN sets.

(2) *Co-channel interference.* Co-channel interference occurs when an aircraft is in a position to receive TACAN signals from more than one ground station on the same frequency. Normally this occurs only at very high altitudes when distance separation between like frequencies is inadequate. DME, azimuth, or identification from either ground station may be received. This is not a malfunction of either air or ground equipment, but a result of interfering signals of two ground facilities.

(3) *False or incorrect lock-on.* False or incorrect lock-on indications in the aircraft can be caused by misalinement or excessive wear of the airborne crystal selector assembly. Selection of a numbered TACAN channel activates a drum and wiper arrangement which rotates until the wiper contacts the proper crystal on the drum. These crystal contact points are very small and close together, and wear or misalinement can cause the wiper to miss the proper crystal and contact the wrong one. This can result in the wrong station or no station being tuned in. When this occurs, rechanneling of the receiver may result in the correct channel being selected.

e. *Precautionary Actions.* The following precautionary actions should be taken by the aviator to guard against in-flight use of erroneous navigational signals:

(1) ALWAYS check the identification of any NAVAID station and monitor it during flight.

(2) ALWAYS use ALL suitable navigational equipment aboard the aircraft and cross-check heading and bearing information.

(3) NEVER overfly preplanned estimated time of arrivals (ETA) without careful cross-check of NAVAIDs and ground checkpoint.

(4) CHECK notices to airmen (NOTAMs) and the Department of Defense (DOD) flight information publication (FLIP) before flight for possible malfunctions or limitations on NAVAIDs to be used.

(5) DISCONTINUE USE of any suspected NAVAID and confirm aircraft position with radar or other equipment.

18-6. AN/ARN-103 TACAN

The AN/ARN-103 TACAN control panel consists of an operation mode-select control, a mode switch, volume control, channel select control and indicator, built-in-test (BIT) capability, BIT indications, and an electronic countermeasures (ECM) indicator (fig 18-8). Refer to the aircraft operator's manual if a different set is installed in the aircraft.

a. *Operation Mode-Select Control.* This control has four positions—OFF, REC, T/R, A/A, and AUTO. The significance of each is as follows:

(1) OFF—all power is removed from the set.

(2) REC—selects receive portion of the set for course information and station identity tone.

(3) T/R—selects transmit and receiver portions of the set for course and distance information.

(4) A/A—The air-to-air circuits in the TACAN transmitter and receiver are

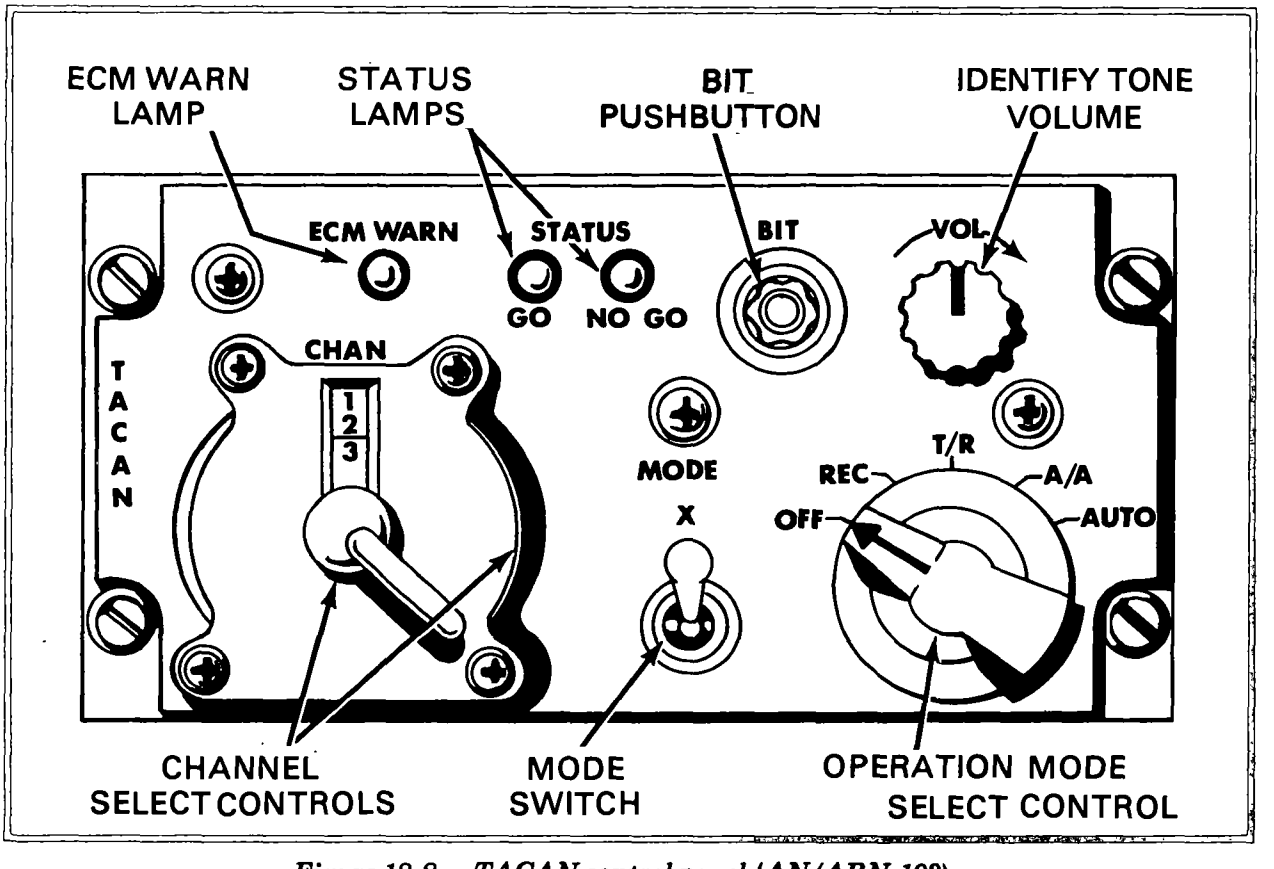


Figure 18-8. TACAN control panel (AN/ARN-103).

activated to determine range to another aircraft equipped with a similar type TACAN. Operation in the A/A position requires prearrangement with cooperating aircraft. Both of the aircraft must be equipped with a TACAN that is set to the A/A position and a 63-channel separation must exist between them.

(5) AUTO—TACAN channels are automatically selected and course and distance information fed directly into the inertial navigation system (INS) providing a continuous INS update.

b. *Mode Switch*—selects X or Y beacon channels. Presently all navigation stations are operating in the X mode; therefore, this switch should be in the X position.

c. *Channel Select Control*—provides selection of one of 126 TACAN channels for receiving and transmitting.

d. *Volume Control*—adjusts volume of the beacon identity tone. The intercom NAV control switch must be positioned ON to receive this tone.

e. *BIT Pushbutton*—initiates built-in, self-test, sequence in the system.

f. *Status Lights (GO NO GO)*—display the status of the system after self-test is initiated.

g. *ECM Light*—indicates when countermeasure system is attempting to jam the system.

18-7. DISPLAY

The methods by which TACAN range and bearing information is displayed will vary from aircraft to aircraft, and the aviator should refer to the appropriate aircraft operator's manual. The following display arrangement is that used by the U-21A and RU-21 (fig 18-9):

a. *Bearing Information.* TACAN bearing information is fed to the pilot's and copilot's radio magnetic indicator (RMI) and course indicators as follows:

(1) RMI. TACAN bearing information is fed directly to the double pointer (#2) needle of the pilot's and copilot's RMI. The pointed end of the needle denotes the magnetic course to the station and the tail of the needle denotes the radial from the station on which the aircraft is presently located. The single (#1) needle is driven either by VHF omnidirectional range (VOR) or automatic direction finding (ADF), depending upon the position of the ADF-VOR switch on the face of the indicator.

(2) *Course indicators.* Bearing information is fed to the pilot's and copilot's course indicators when their respective course selector switches are placed in the TACAN position.

Note. **The TACAN resolver circuitry is incorporated in the pilot's course indicator and all TACAN courses**

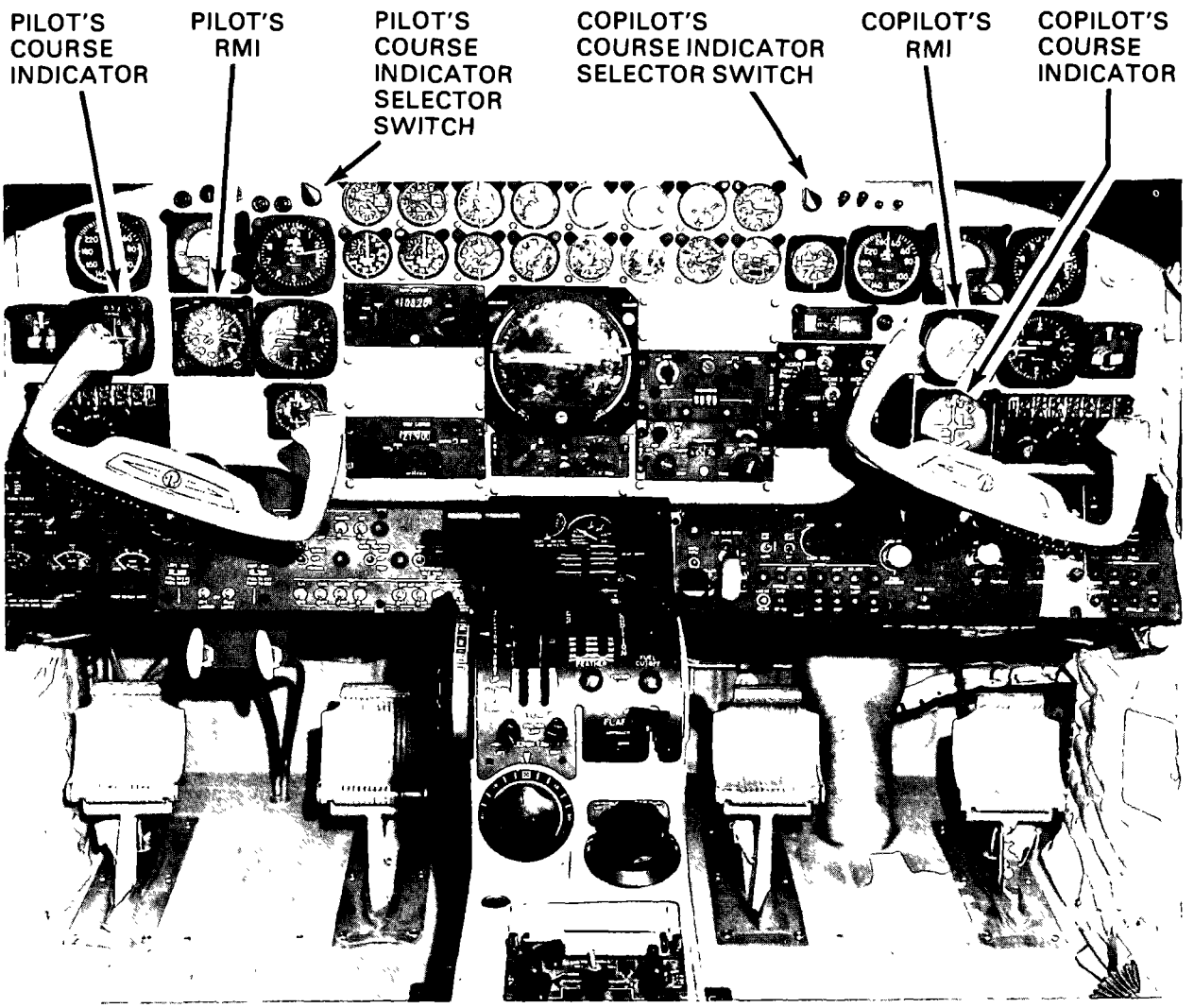


Figure 18-9. Display of TACAN bearing information (U-21A airplane).

must be set in the pilot's indicator. When the copilot's course selector switch is placed in the TACAN position, all course deviations are in respect to the course in the pilot's indicator regardless of the copilot's course indicator setting. Conversely, the VOR resolver circuitry is incorporated in the copilot's course indicator and all VOR courses must be selected from that position. In the VOR position, the pilot's indicator displays deviations in respect to the copilot's setting.

b. *Range Information.* Slant-range distance in NM to or from a TACAN station is displayed on the 339D-1 range indicator in U-21 airplanes (fig 18-10) and on the bearing distance heading indicator (BDHI) in OV/RV-1 airplanes (fig 18-9a). The indicator is interpreted as follows:

(1) The first digit indicates range in 100 NM increments.

(2) The second digit indicates range in 10 NM increments.

(3) The third digit indicates unit components of range continuously from 0 to 9 NM.

(4) The fixed index provides a reference for reading the continuous dial.

(5) A bar covers the dials during search operations or when the function switch is in any position other than R/T or A/A. The dials continuously rotate during search operations.

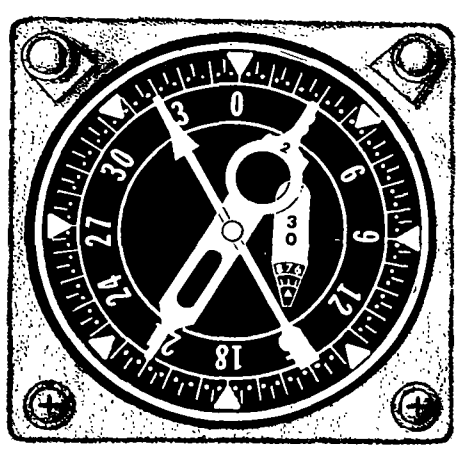


Figure 18-9a. Bearing distance heading indicator (BDHI).

18-8. PREFLIGHT CHECK

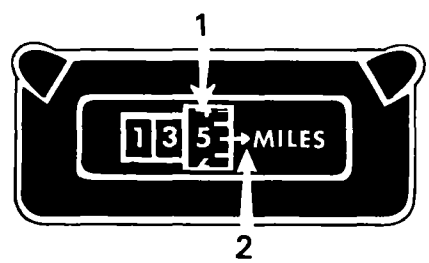
The TACAN should be tuned and checked prior to takeoff. The check should use the built-in test feature of the set and (if possible) a ground check using a certified ground checkpoint.

a. *Built-in Test Procedure.*

(1) Select any channel on which no strong station signals are being received.

(2) Place operation mode select control to T/R.

(3) Press BIT button momentarily to initiate built-in test. ECM WARN, GO and NO GO lights will illuminate while the BIT button is depressed, providing a lamp



1. DISTANCE IN NAUTICAL MILES

2. FIXED REFERENCE

Figure 18-10. TACAN distance indicator 339D-1.

test and indicating beginning of the self-test.

(4) The pointed end of the selected RMI needle should indicate 360°.

(5) With the TACAN course selector set to 360°, the deviation indicator, coupled to TACAN, should center with a TO ambiguity indication.

(6) Distance indicator should move to 000 miles range.

(7) Check GO NO GO status lights. If no malfunctions are detected during the 20-second test cycle, the GO light will illuminate momentarily to indicate completion of a satisfactory test. If a malfunction is detected during the test cycle, the NO GO light will illuminate and remain on until the test cycle is completed.

b. *Ground Test Procedure.*

(1) Select a local TACAN channel.

(2) Place operation mode select control to T/R.

(3) Position aircraft over checkpoint. Most airfields with a TACAN station in the local area will have ground-check information posted in different runup areas denoting the radial and distance to the station.

c. *Radial Check.* The tail of the selected RMI needle should point to the posted radial ± 4°, and the course selector should center ±4° with a FROM ambiguity indication when the posted radial is set in the course selector.

d. *Distance Check.* The range indicator should read the posted distance within ± ½ mile or 3 percent of the distance to the facility, whichever is greater.

18-9. GENERAL TACAN NAVIGATIONAL PROCEDURES

Since TACAN presents bearing information in the same manner as VOR, there is no change in the procedures used for orientation, track interception, tracking, etc. The procedures presented in this chapter will be those used to take advantage of range information presented by TACAN.

18-10. DETERMINING STATION PASSAGE

Because of the large TACAN azimuth cone of confusion, an inaccurate determination of station passage will result when using the TO-FROM indicator reversal or RMI needle reversal. The most accurate method of determining passage is by noting when the range indicator stops decreasing. Flying directly over the station, the range indicator will stop decreasing when it indicates the approximate aircraft altitude above the station in NM. *For example,* an aircraft flying at 12,000 feet above ground level (AGL) is at an altitude of approximately 2 NM (6,000 feet approximates 1 NM); therefore, the range indicator should stop decreasing when it

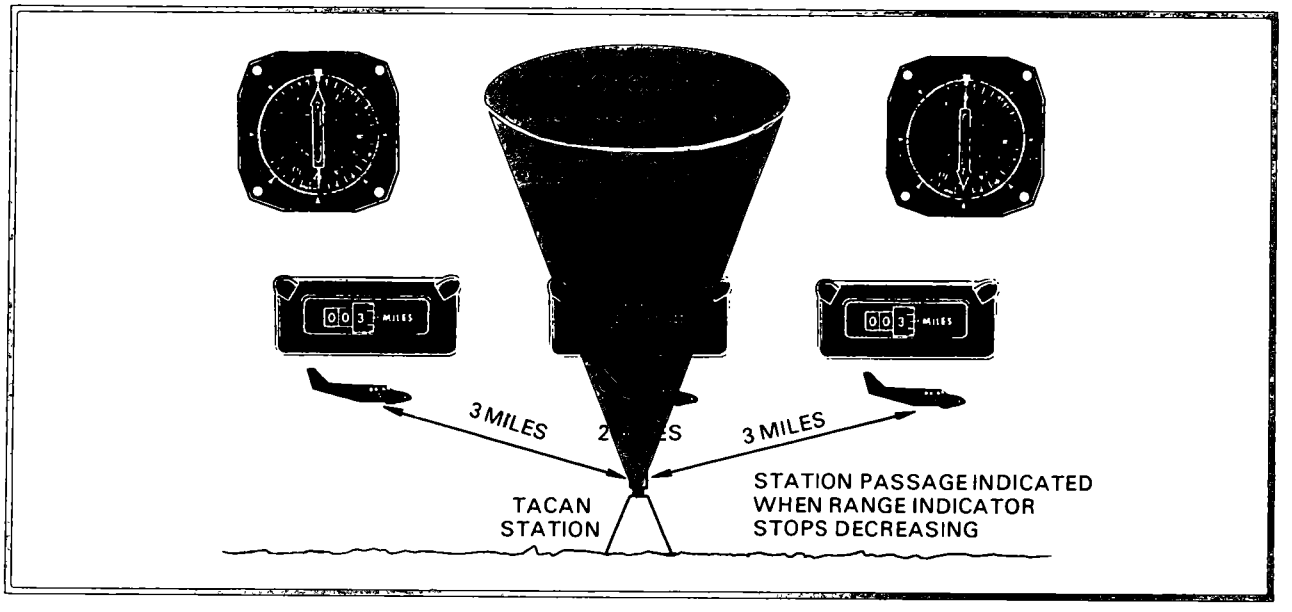


Figure 18-11. Indication of station passage.

indicates approximately 2 NM (fig 18-11). At altitudes of 5,000 feet AGL or less, the reversal of the sense indicator is accurate enough at ATC estimates.

18-11. [illegible]

A groundspeed check can be made while maintaining a course to or from a TACAN station. As a guide, however, groundspeed checks should be performed only when the aircraft's slant-range distance is more than the aircraft altitude divided by 1,000. *For example*, if the aircraft is at 10,000 feet, groundspeed checks should be performed only when 10 or more NM from the station. Checks made below 5,000 feet can be considered accurate at any distance from the station. To perform the groundspeed check, begin timing when the range indicator shows a whole number. After a predetermined time has elapsed, check the range indicator and note the distance flown. On a computer, set the distance flown over the elapsed time in minutes and read the groundspeed above the 60 index (fig 18-12). The longer the elapsed time, the more accurate will be the computed groundspeeed. To determine groundspeed without using the computer, multiply distance flown in 2 minutes by 30, 3 minutes by 20, 6 minutes by 20, and 12 minutes by 5.

[illegible]

When using TACAN, intersections can easily be established without cross-tuning different stations by placing the course depicted on the enroute chart in the pilot's course selector and observing the published

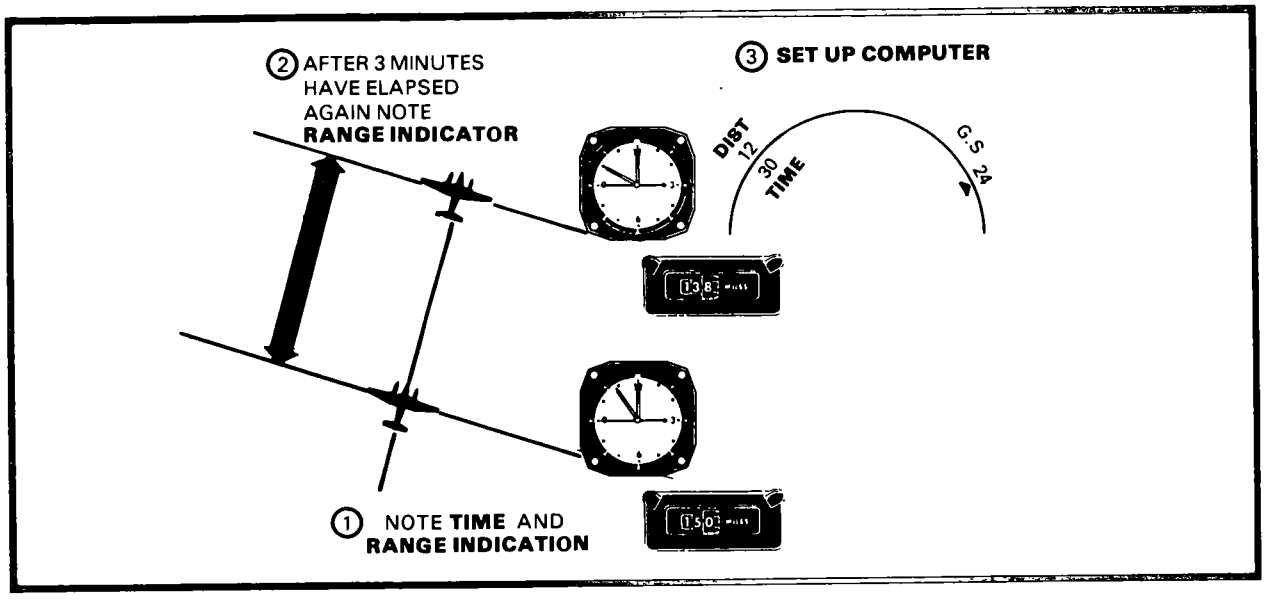


Figure 18-12. TACAN groundspeed checks.

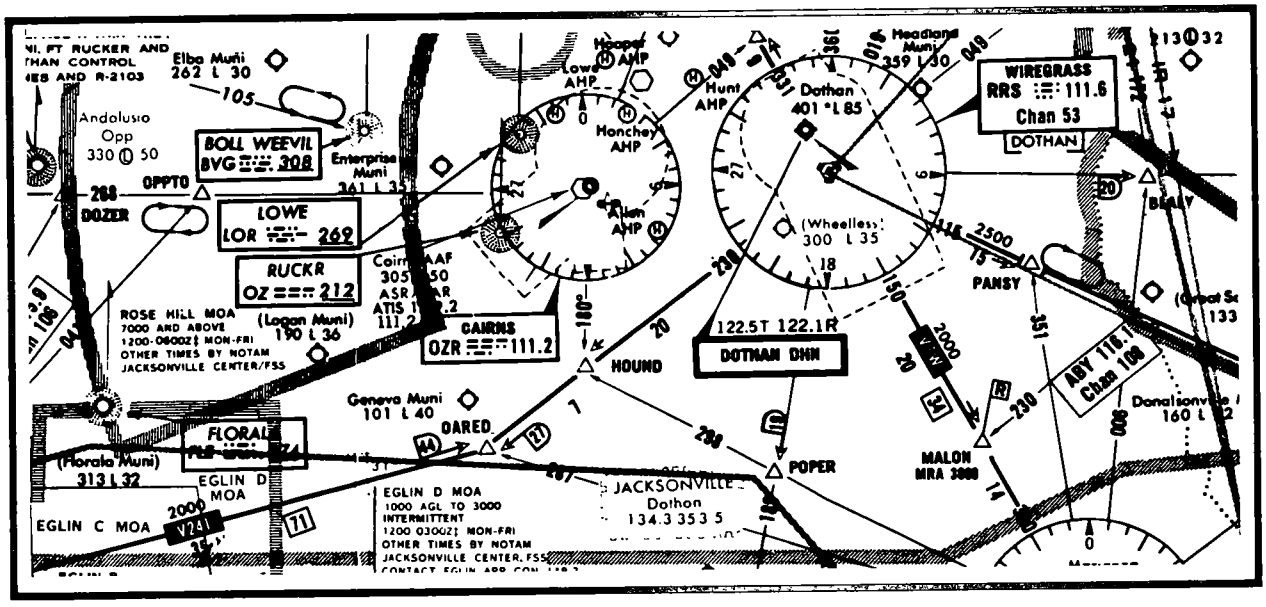


Figure 18-13. DME mileage depiction.

DME reading for the desired intersection. *For example*, assume you are tracking outbound from Wiregrass VORTAC on V-241 (fig. 18-13) and wish to establish Hound and Dared intersections. With 230° set in the pilot's course indicator and a centered needle, you will be over Hound intersection when the distance indicator reads 20 NM and Dared intersection when the reading is 27 NM.

18-13. TACAN ARCS

a. *Definition.* TACAN arcs are lines of constant radial distance from a TACAN station and are sometimes flown during departures and approaches. Arc instructions are given as "via (number of miles) mile arc, direction (north, east, etc.) of (name of NAVAID)." An example of this is "Via 10-mile arc east of Wiregrass VORTAC."

b. *Uses.* TACAN arcs are used primarily for instrument approaches and departures. Approach procedures are depicted in the instrument approach procedures of DOD FLIP, and departure procedures are depicted in standard instrument departures (SID) or may be issued by departure control. Three typical uses of TACAN arcs are—

(1) *Transition to a final approach radial.* The approach depicted in figure 18-14 would be executed by flying the published radial inbound from the initial approach fix until intercepting the 12 DME-mile arc. This arc would be maintained until the final approach radial was intercepted, at which time the pilot would turn inbound on final approach. The final approach fix would be established when the range indicator showed 5 NM and the missed approach point would be indicated by a 1.5 NM reading.

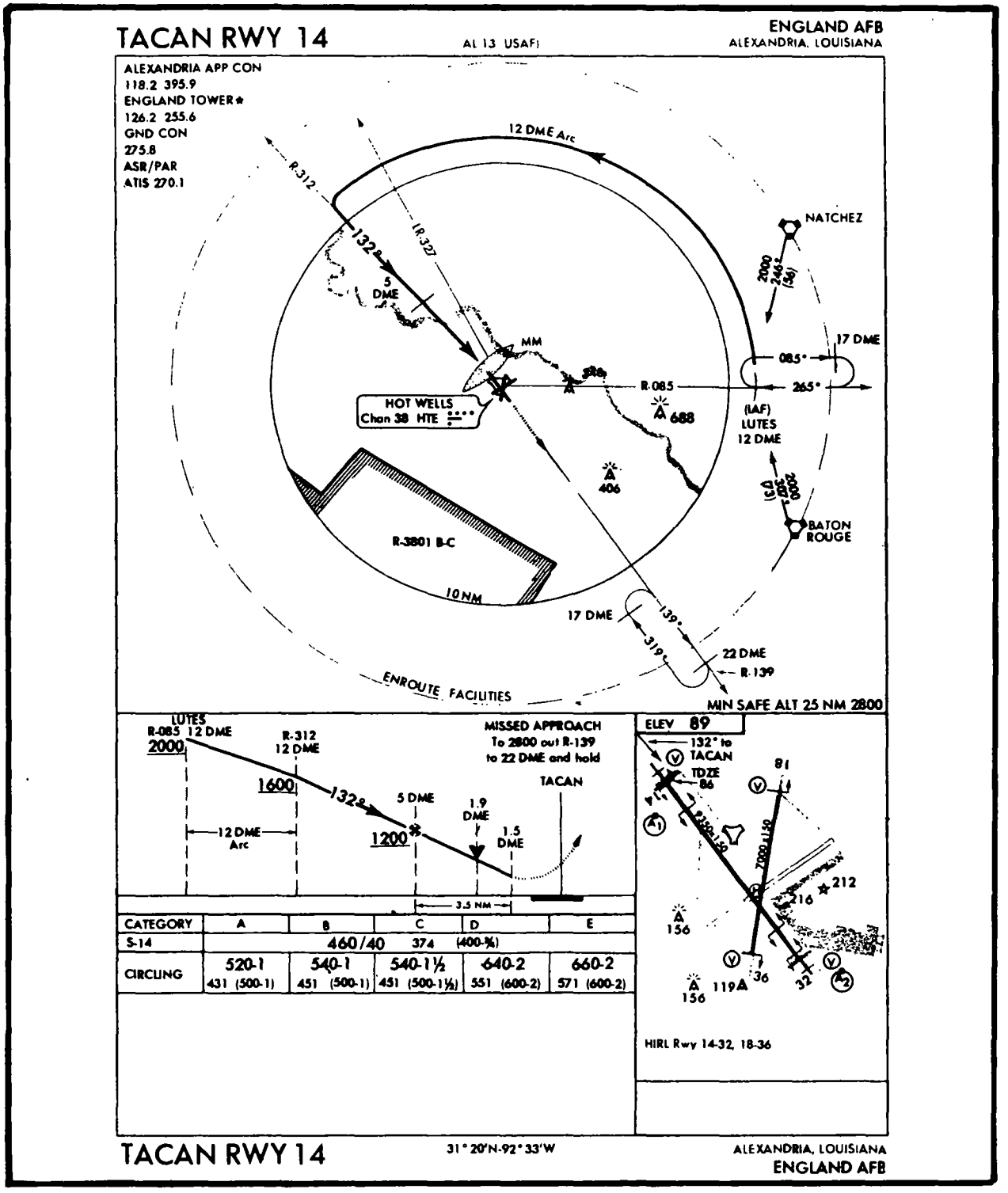


Figure 18-14. TACAN arc used to transition to final approach radial.

(2) *Entire final approach pattern.* The approach depicted in figure 18-15 would be executed by flying a course of 151° outbound from Westminister VORTAC until intercepting the 14.8 DME-mile arc. The 14.8-mile arc would then be maintained throughout the approach until reaching the missed approach fix. The final approach fix would be established by setting 036° in the pilot's course indicator and awaiting a centered needle. The missed approach fix would be indicated by a centered needle with 054° set in the pilot's course indicator.

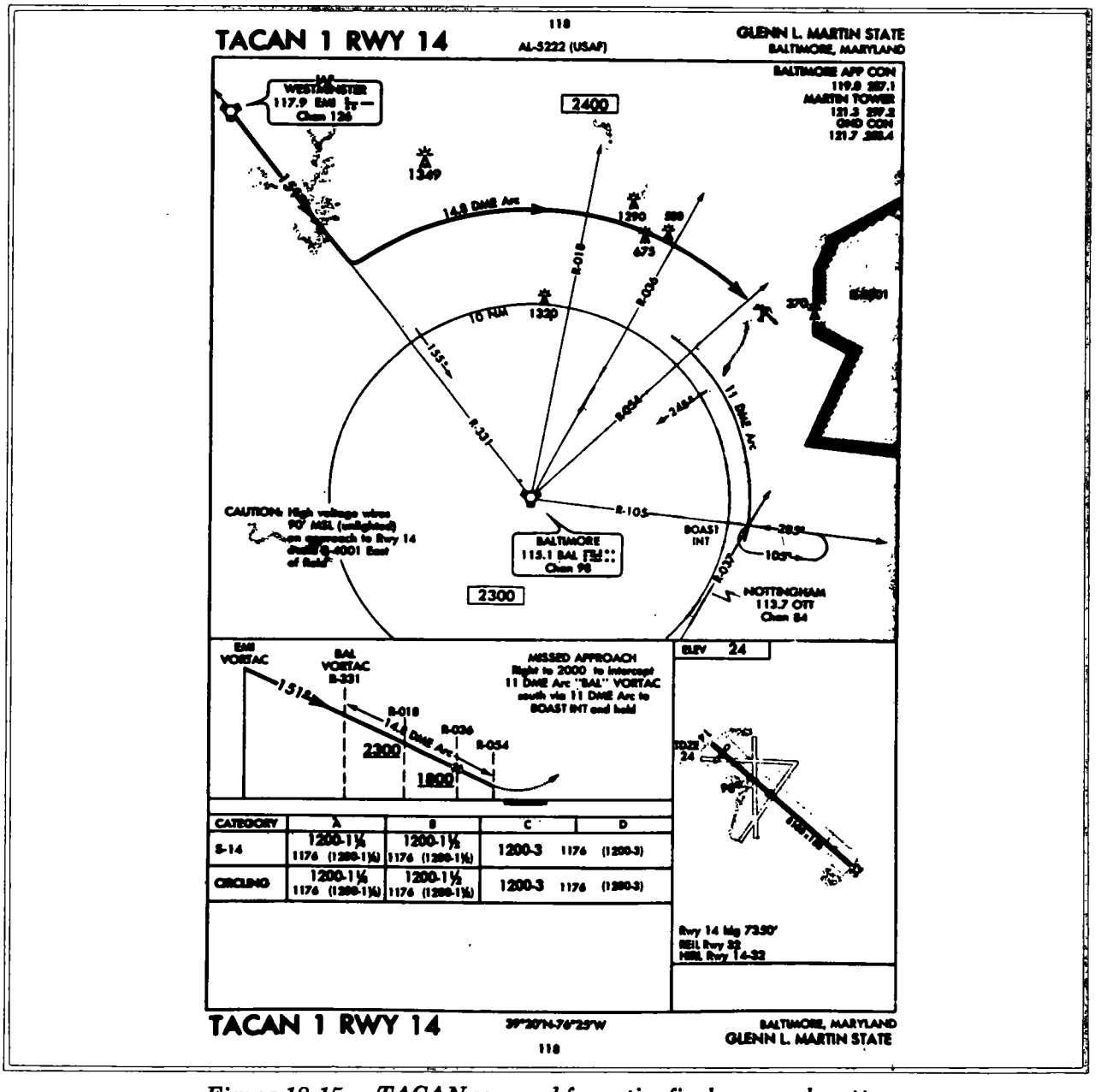


Figure 18-15. TACAN are used for entire final approach pattern.

(3) *TACAN departures.* A TACAN departure (fig 18-16) could be a portion of a SID or it could be described by departure control. The controller would issue (in essence) the following instructions concerning such a departure: "After takeoff, track outbound on the 080° radial until intercepting the 10-DME-mile arc east of the station; a left turn to maintain the 10-DME-mile arc; intercept and track outbound on the 030° radial."

c. *Arc Interceptions.* To intercept a TACAN arc (fig 18-17) from a radial (maintaining course inbound or outbound), a turn of approximately 90° is required to place the bearing pointer on the wingtip toward the station, with the range indication equal to the desired arc. A good technique to determine the leadpoint for a 90-degree arc interception is to lead the desired arc one-half percent of the groundspeed for a standard rate (3° per second)

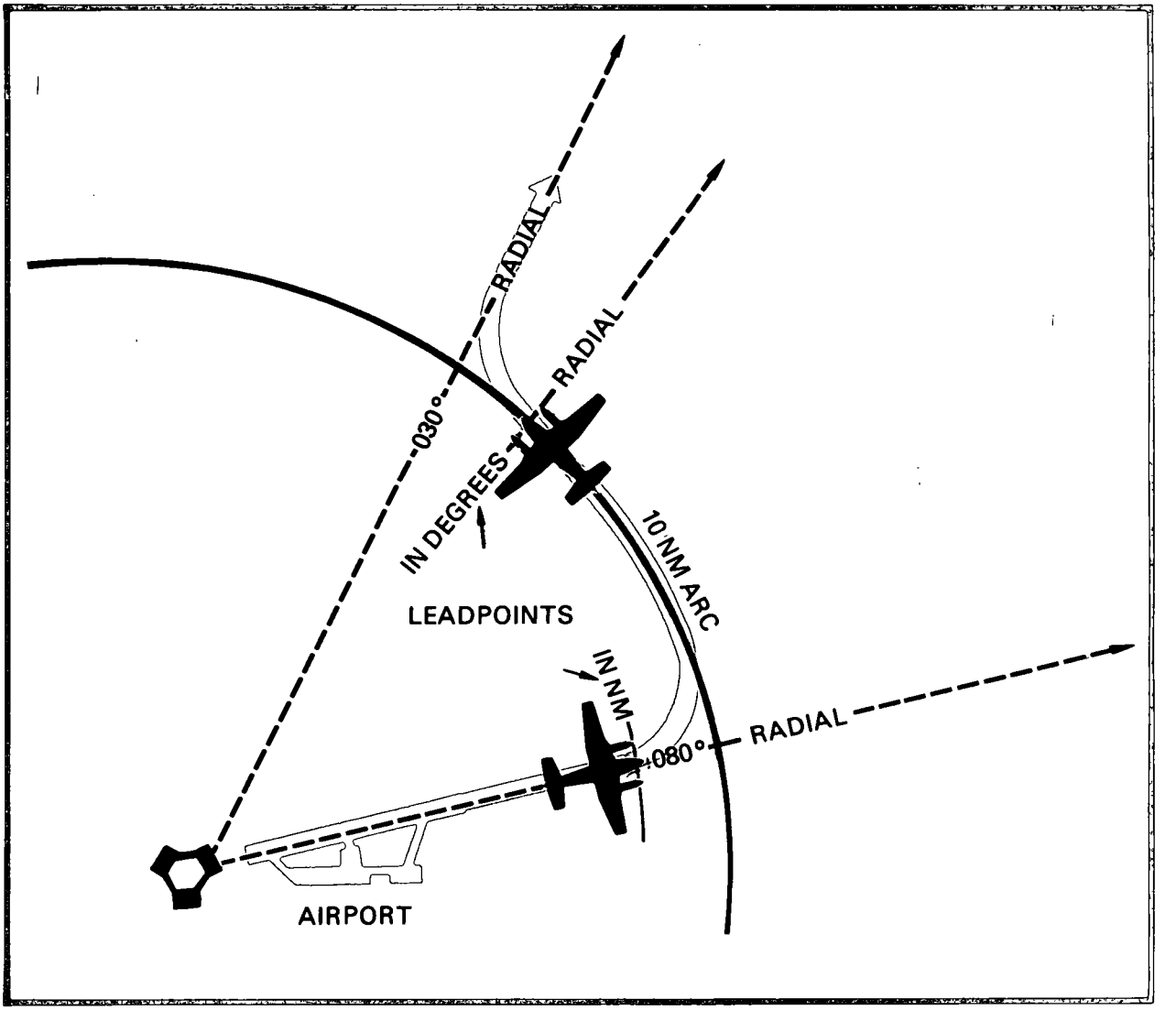


Figure 18-16. TACAN departure.

turn or 1 percent of the groundspeed for a half-standard rate (1 1/2° per second) turn. *For example,* with a 200-knot groundspeed the amount of lead would be 1 NM for a standard rate turn and 2 NM for a half-standard rate turn. The turn to intercept the arc should be started when the range indication is equal to the radius of the arc plus or minus the lead. Add the lead to the radius of arc when intercepting the arc from an inbound course to the station, and subtract it when intercepting the arc from an outbound course. During the last 30° of turn, the bearing pointer and range indicator must be monitored to determine when to roll out. If it appears that the turn will not be completed at the desired range, roll out with the bearing pointer ahead of the wingtip to decrease the range, or behind the wingtip to increase the range.

d. *Maintaining Arcs.* In theory it is simple to fly a TACAN arc by maintaining

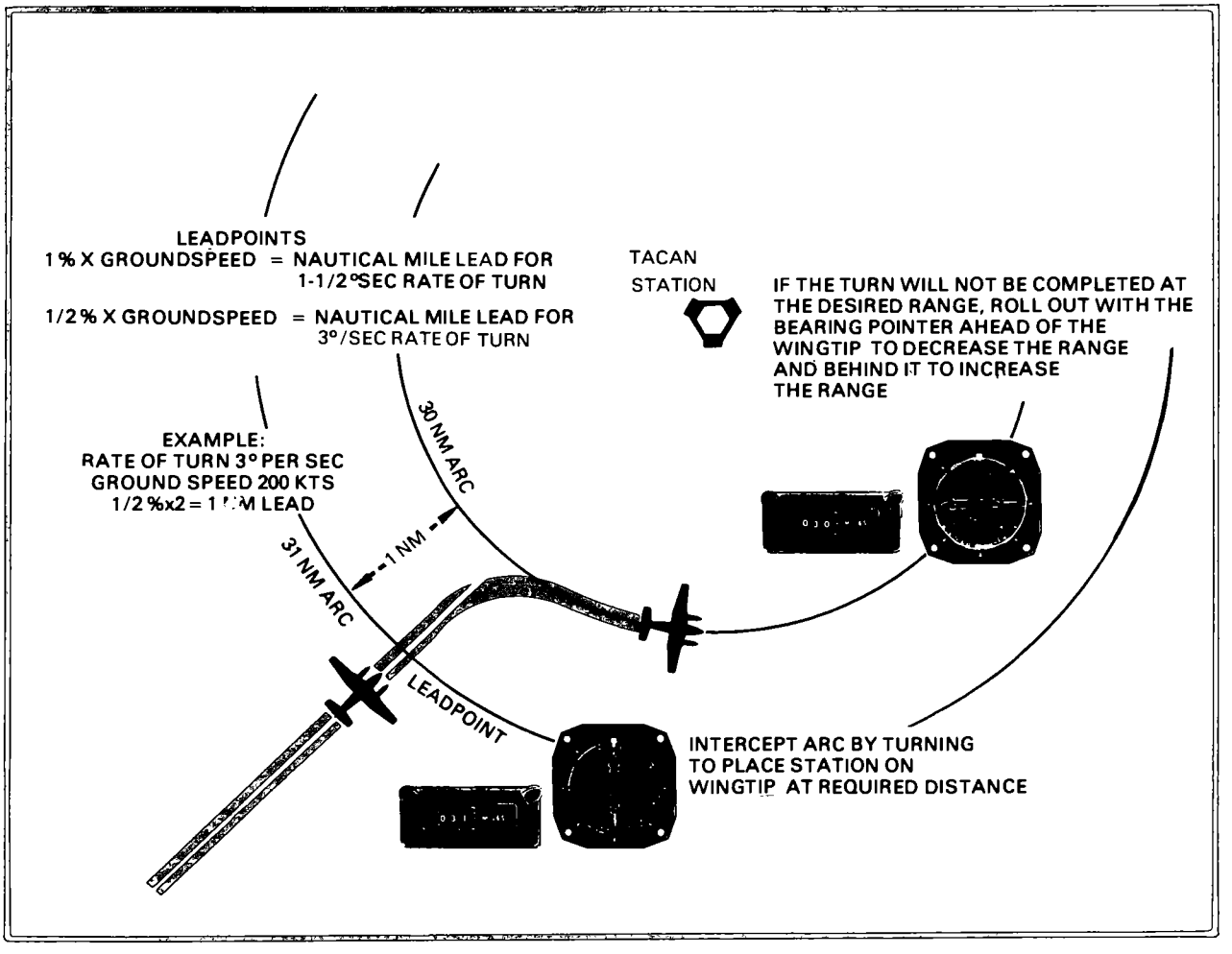


Figure 18-17. Intercepting TACAN arcs.

a relative bearing of 90° or 270° (fig 18-18). In practice this can be difficult, since the exact rate of turn necessary will vary with distance from the facility, the airpeed of the aircraft, and drift in crosswind conditions. A good procedure is to fly a series of short legs, keeping the bearing pointer on or near the wingtip position and making corrections, as necessary, with reference to the distance shown by the range indicator. *For example*, with the bearing pointer on the wingtip and the aircraft at the desired range, maintain heading and allow the bearing pointer to move 5° to 10° behind the wingtip position. This will cause the range to increase slightly. Next, turn toward the station to place the bearing pointer 5° to 10° ahead of the wingtip and maintain this heading until the bearing pointer is again behind the wingtip. Corrections from the inside are assisted by the arc curving toward the aircraft; if outside the arc, greater corrections will be needed to return. The aviator must continually monitor the range indicator and make adjustments in heading to maintain the desired arc.

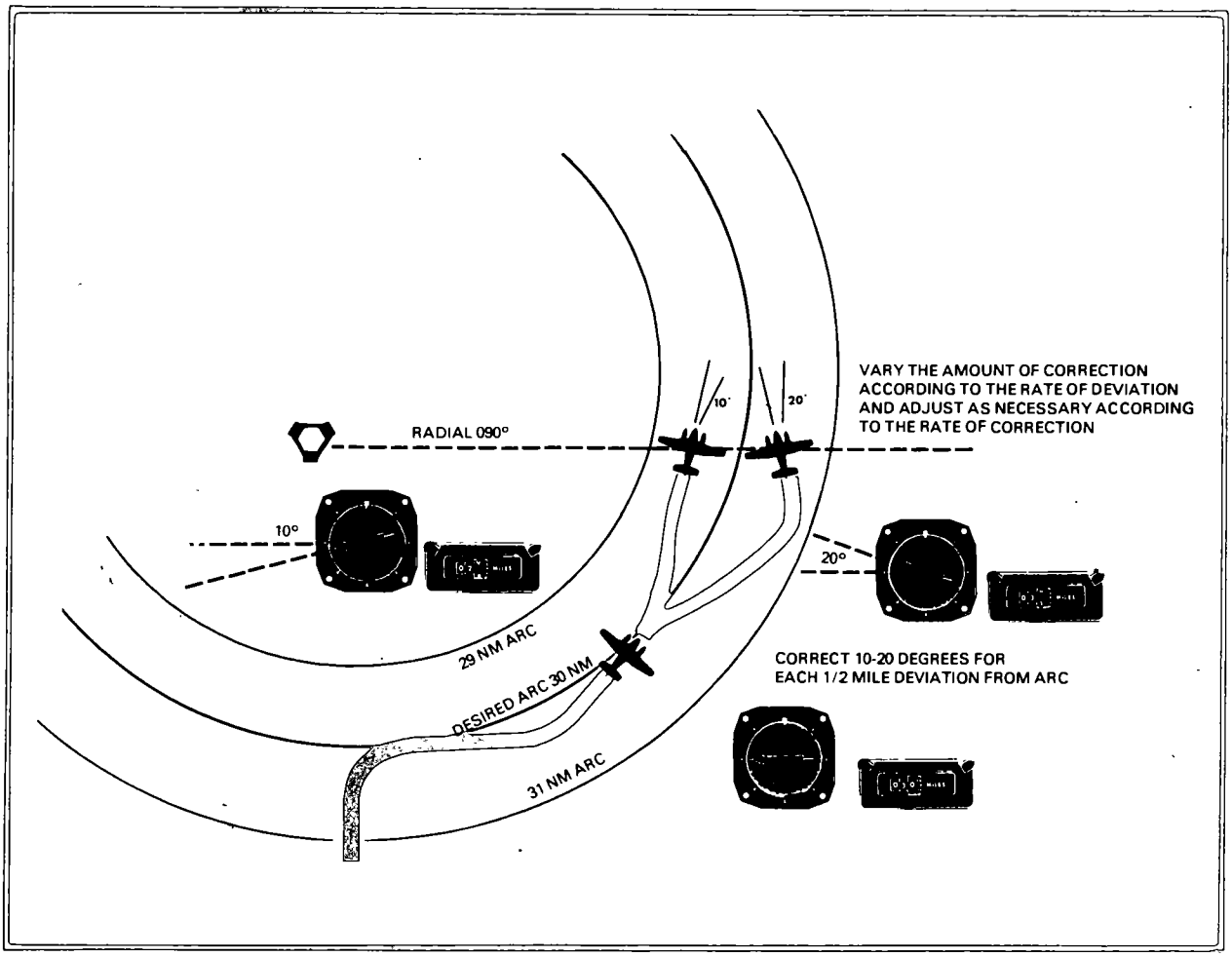


Figure 18-18. Maintaining TACAN arcs.

e. *Intercepting a Radial From an Arc.* To intercept a radial from an arc, set the desired course in the course selector window as soon as practical. Monitor the rate of bearing pointer movement while flying the arc; the interception angle will be approximately 90°. Changing the leadpoint used for the arc interception ("c" above) from NM to degrees is a technique that can be used to determine an approximate leadpoint. Use the relationship that 1° is 1 NM wide at 60 NM from the station and its width increases or decreases in proportion to the distance (fig 18-19). *For example,* with a 150-knot groundspeed (using a standard rate turn), a three-fourth NM leadpoint would be used to intercept the 15 NM arc. Since 1° of travel along the 15 NM arc represents one-fourth NM, the leadpoint when intercepting a radial from the arc (no wind) would be 3° (fig 18-20).

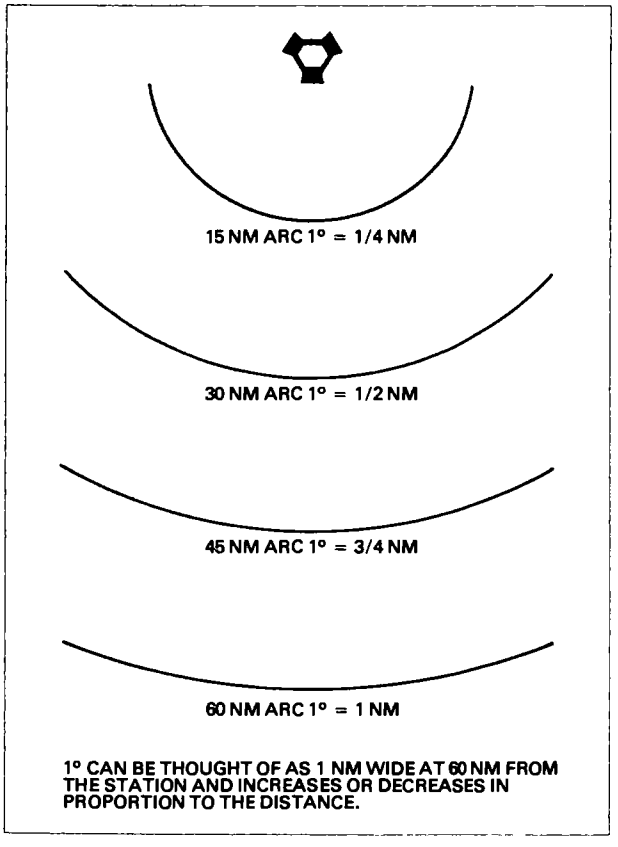


Figure 18-19. Degree-distance relationship along a TACAN arc.

TACAN holding (fig 18-21), using distance instead of time, provides a virtually unlimited number of holding fixes available at each facility. Due to the cone of confusion, holding is normally accomplished a considerable distance from the station. The direction of holding is relative to the holding fix (radial/distance) rather than the TACAN facility. Once in the holding pattern, turns are initiated at the indicated range published or issued by the controller. The inbound course to the holding fix should be set in the course selector window. Since the holding pattern may be a considerable distance from the TACAN station, course corrections to intercept course prior to reaching the holding fix will be larger than those normally used in VOR or ADF holding. *For example,* 6° off course at 30 miles is a 3-mile course error; whereas 6 ° off course at 10 miles is only a 1-mile course error. (Refer to chapter 19 for detailed holding procedures (fig 18-21).)

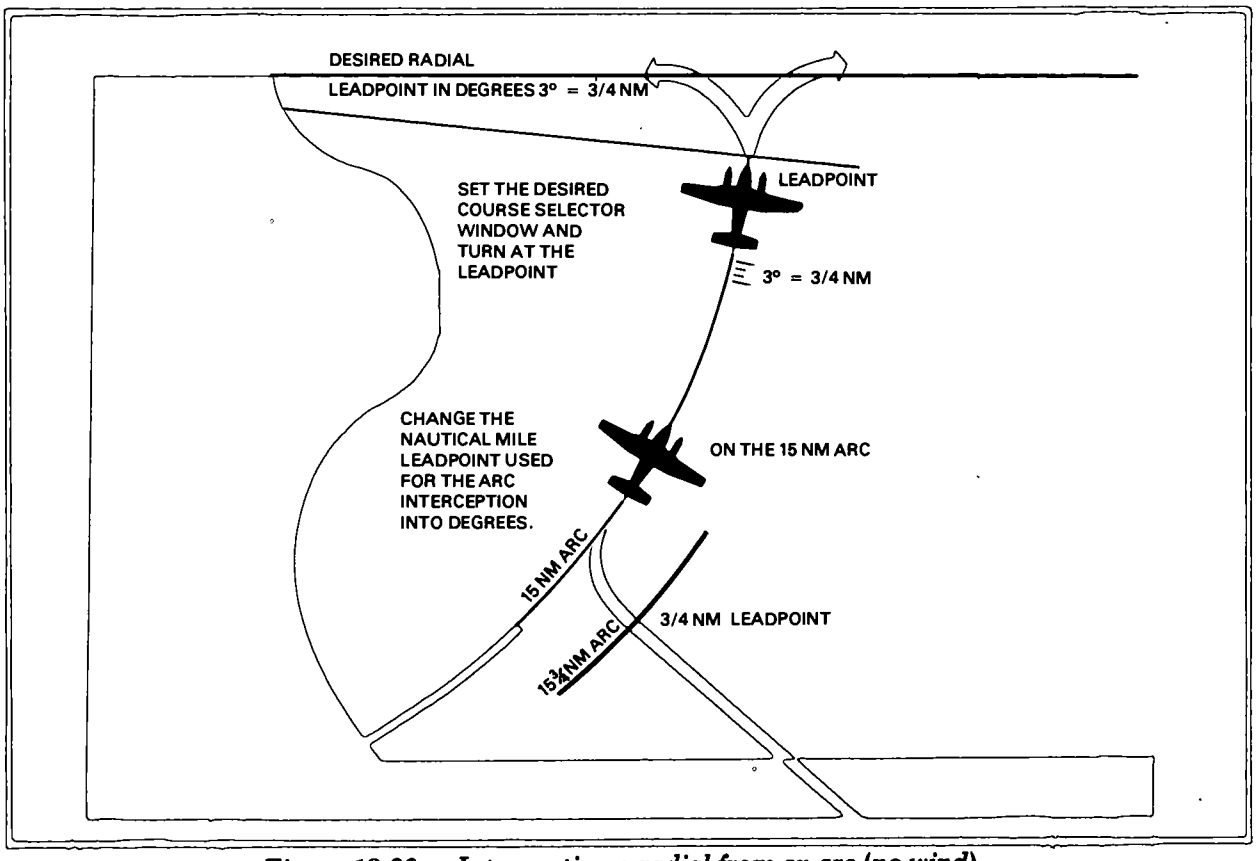


Figure 18-20. Intercepting a radial from an arc (no wind).

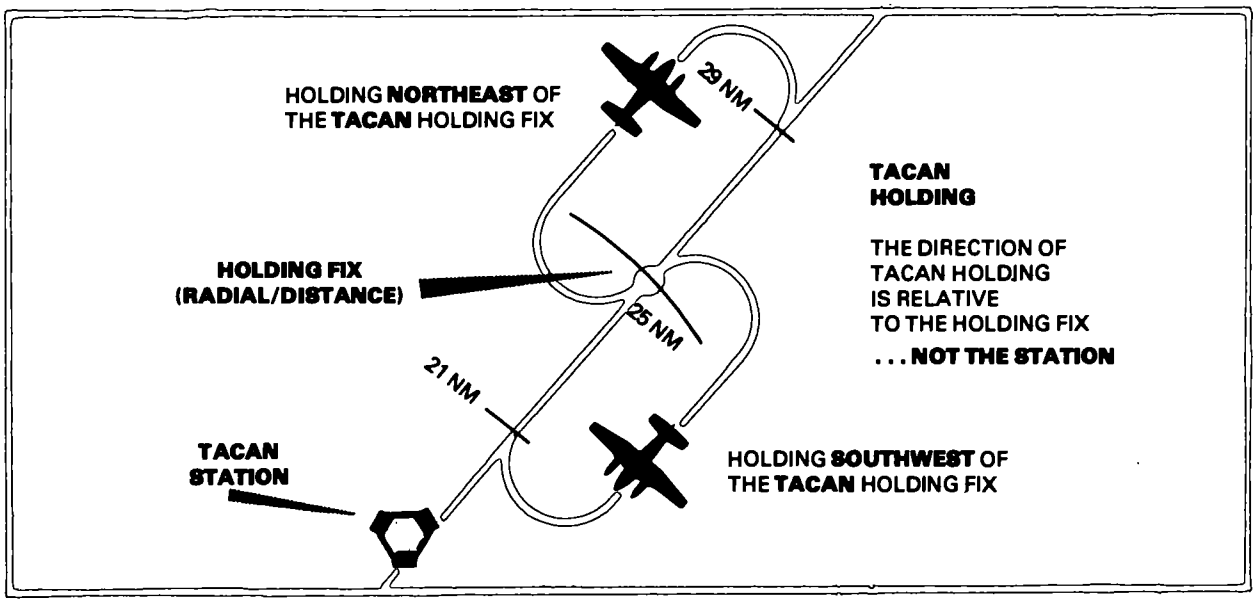
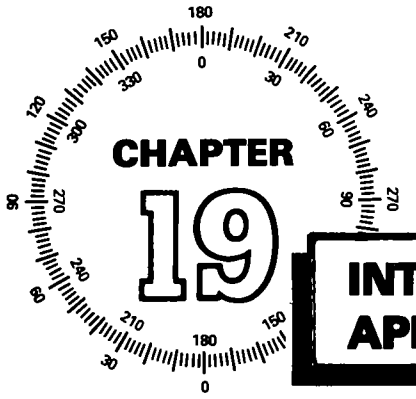


Figure 18-21. TACAN holding.



CHAPTER 19

INTRODUCTION TO INSTRUMENT APPROACH PROCEDURES

Section I. INSTRUMENT APPROACHES

19-1. PURPOSE

Instrument approaches are designed to assist the aviator in landing during low ceiling and low visibility conditions by—

a. Allowing movement from enroute courses and altitudes to a position and altitude at which the final descent on a final approach course can be started.

b. Providing for safe descent on the final approach course with accurate directional guidance.

c. Guiding the aircraft down on the approach path to a minimum altitude from which a safe landing can be made if the aviator has visual reference to the runway.

An instrument approach procedure may have four separate segments (fig 19-1). These include initial, intermediate, final, and missed approach segments. In addition, an area for circling the airport under visual conditions shall be considered. The approach segments begin and end at designated fixes; however, under some circumstances certain segments may begin at specified points where no fixes are available. The fixes are named to coincide with the associated segment. *For example,* the intermediate segment begins at the intermediate fix (IF) and ends at the final approach fix (FAF). The segments are discussed in the same order in this chapter that the pilot would fly them in a complete procedure (i.e., from an initial; through an intermediate; to a final approach, and the missed approach if required). Only those segments which are required by local conditions are included in a procedure. The design of the approach should blend all segments to provide an orderly maneuvering pattern to the local area with regard to obstruction protection and airspace considerations.

a. *Feeder Route.* The feeder route, when required, is used to designate course and distance from a fix in the enroute structure to the initial approach fix (IAF).

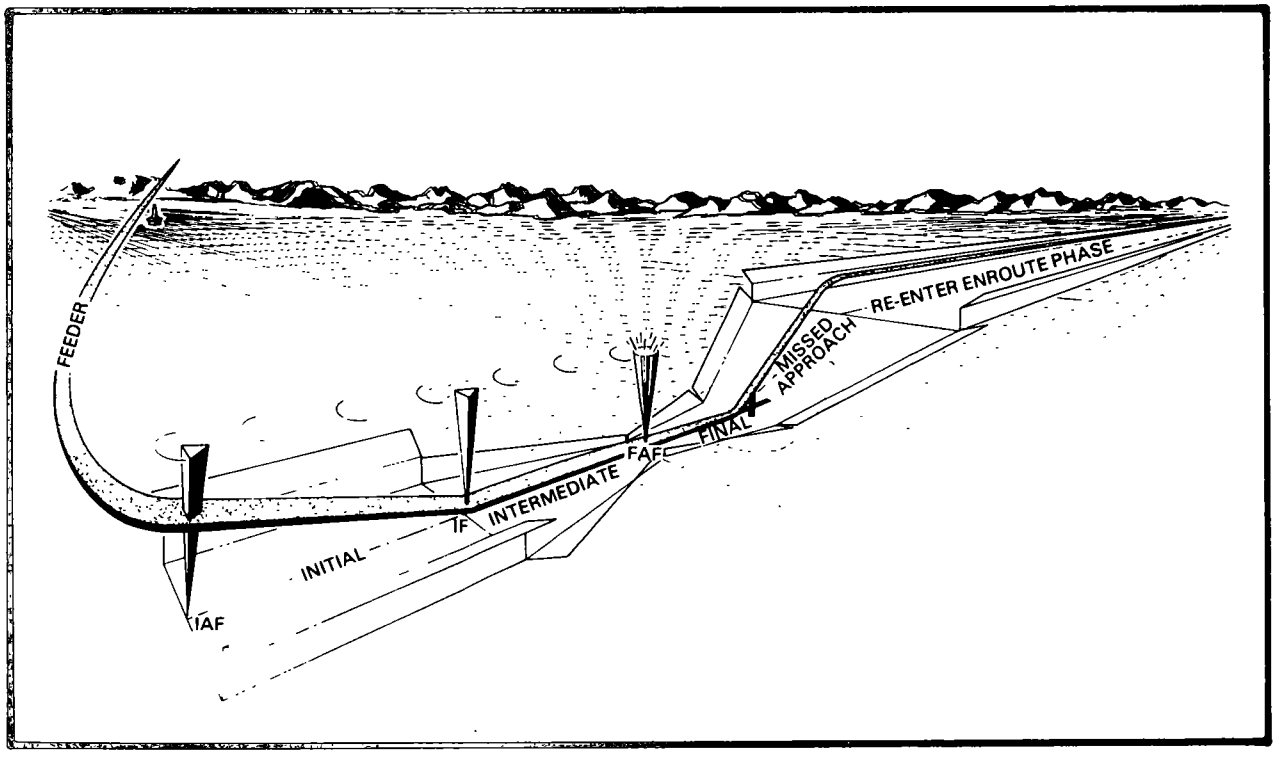


Figure 19-1. Segments of an approach procedure.

Only those feeder routes normally used which provide an operational advantage are established and published.

b. *Initial Approach Segment.* In the initial approach, the aircraft has departed the en route phase of flight and is maneuvering to enter the intermediate segment. An initial approach may be made along an arc, radial, course, heading, radar vector, or any combination thereof. Procedure turns, holding pattern descents, and high altitude penetrations are also initial segments.

c. *Intermediate Approach Segment.* This is the segment which blends the initial approach segment into the final approach segment. It is the segment in which aircraft configuration, speed, and positioning adjustments are made for entry into the final approach segment. The intermediate segment begins at the intermediate fix or point and ends at the FAF. There are two basic types of intermediate segments—the radial or course and the arc. When radar vectors are used, the vector course to the final approach course constitutes the initial segment and the flight along the final approach course to the FAF is the intermediate segment.

d. *Final Approach Segment.* This is the segment in which alinement and descent for landing are accomplished. The final approach segment considered for obstruction clearance begins at the final approach fix, or point, and ends at the missed approach point. Final approach may be made to a runway for a straight-in landing, or to an airport for a circling approach.

e. *Missed Approach Segment.* A missed approach segment begins at the missed approach point and provides obstruction clearance and course guidance to a fix for holding or return to the enroute structure. The missed approach point specified in the approach procedure may be the point of intersection of an electronic glidepath with a decision height (DH) or minimum descent altitude (MDA), a navigation facility, a fix, or a specified distance from the final approach fix.

19-3. STRAIGHT-IN APPROACHES

In figure 19-2, an aircraft nearing Robinsville VORTAC requests and receives clearance for a VOR Runway 9 approach to Smithdale airport. Over the Robinsville VOR (IAF), the aircraft begins descent and descends to 2,000 feet while flying between Robinsville VOR and Jones intersection (the initial approach segment) on the Robinsville VOR 135° radial. The term "NO PT" (no procedure turn) appears on the course between Jones intersection and Smithdale VOR indicating that when cleared for VOR Runway 9 approach from this direction, the pilot shall not fly a procedure turn. (See paragraph 19-4 for an approach using a procedure turn.) The aircraft descends to 1,300 feet between Jones intersection and Smithdale VOR (intermediate approach segment) on the 270° radial. After passing Smithdale VOR (FAF), inbound to the airport on the 090° radial, the aircraft begins its final descent to minimum descent altitude published on the approach chart. During the descent from 1,300 feet to landing minimums, the

pilot should expect to establish visual contact with the runway environment and be in position to complete the visual landing. If visual contact with the runway environment is not made or cannot be maintained by the time the aircraft has reached the missed approach point, the missed approach procedure will be executed. Straight-in approaches are required, unless otherwise authorized by air traffic control (ATC), (1) where the procedure specifies "NO PT" or "FINAL," (2) when a radar controller vectors the aircraft on a radar initial approach to a final approach fix or a position on the final approach course, or, (3) when the controller specifies in the approach clearance "cleared for straight-in (type) approach" although "NO PT" is not charted and the aircraft is not being radar vectored.

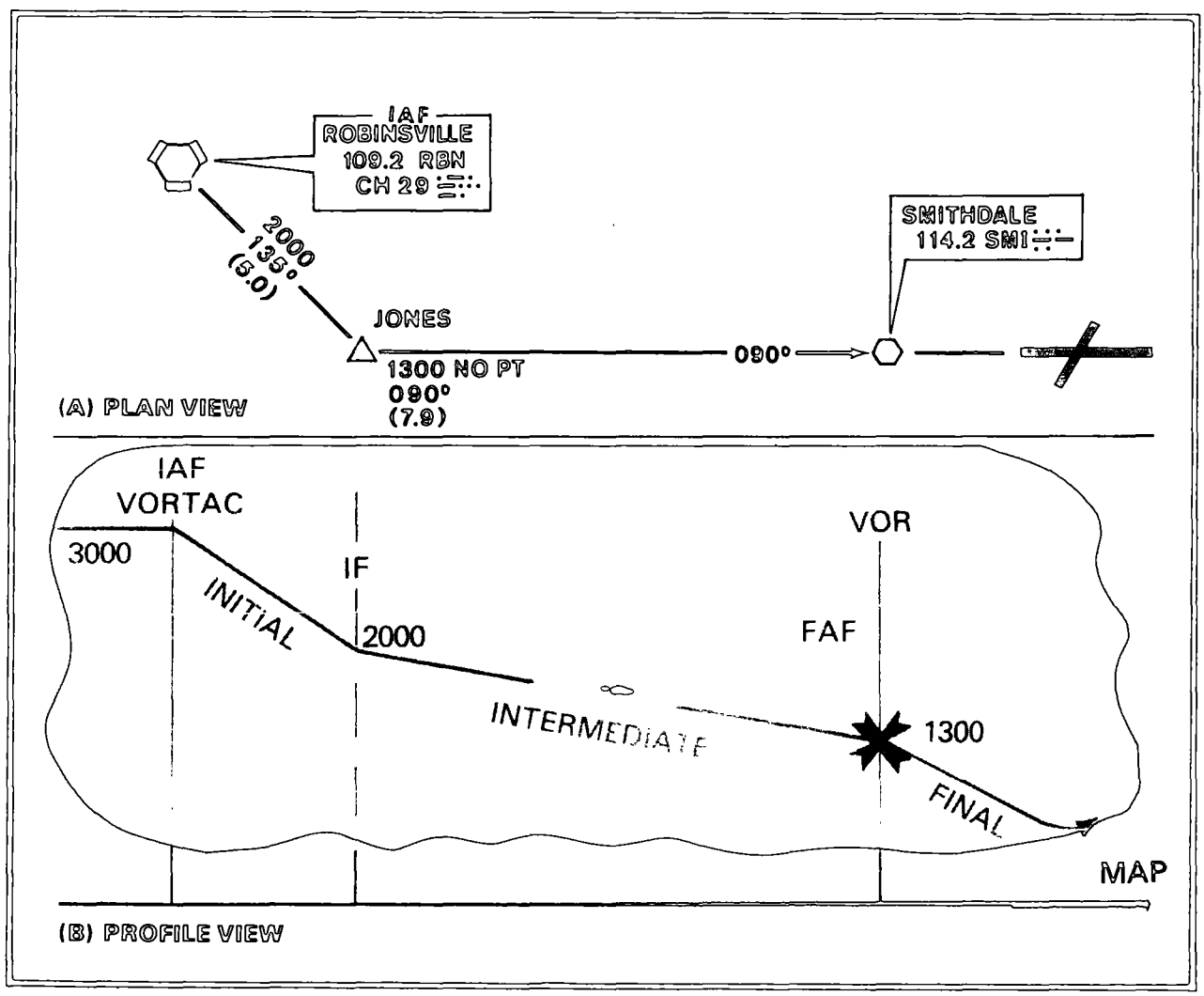


Figure 19-2. Straight-in approach.

Note. **The term "straight-in approach" as used in this paragraph refers to an instrument approach procedure that does not include a procedure turn. It should not be confused with "straight-in landing." An aircraft may execute a "straight-in approach" to a specified runway and then circle to another runway for landing. Circling minimums will be applied in this case. Straight-in landing minimums apply, when published on the approach chart, and a landing is to be made on the runway specified in the air traffic control clearance and contained in the procedure chart title.**

19-4. INSTRUMENT APPROACH WITH PROCEDURE TURN

In figure 19-3, an aircraft is approaching Smithdale VOR from a direction not suited for a straight-in approach. In this case, the approach will require a procedure turn. The aircraft is cleared for a VOR approach while en route from Brown VOR to Smith VOR ((A), fig 19-3). If the aircraft is flying at an altitude above the published feeder route altitude (3,000 feet, fig 19-3), the aviator is cleared to descend to the feeder route altitude upon receiving approach clearance. The initial approach begins when the aircraft crosses Smithdale VOR (IAF)

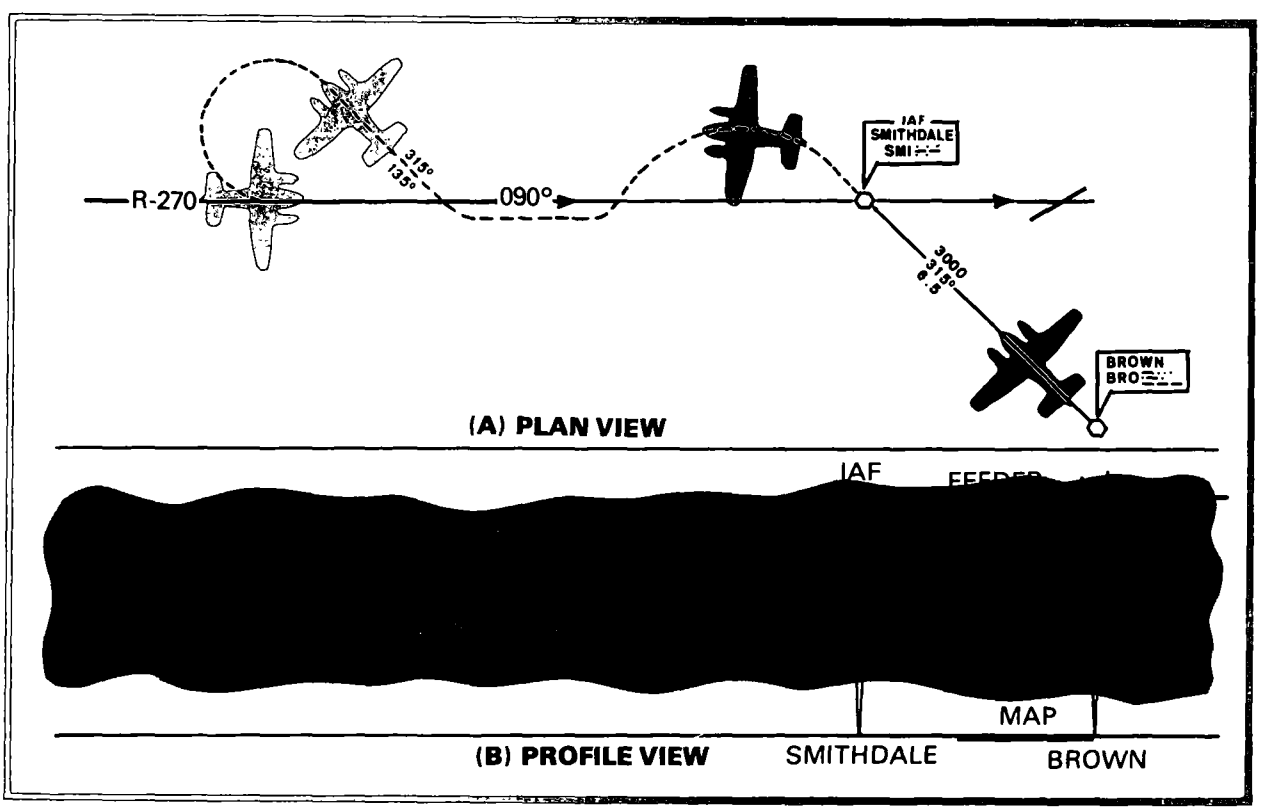


Figure 19-3. Approach with a procedure turn.

outbound. As the aircraft flies outbound for a procedure turn, it descends to 1,800 feet ((B), fig 19-3). After completion of procedure turn (para 19-8 through 19-13), the aircraft begins the intermediate approach segment and descends to 1,300 feet. The final approach segment begins after passing Smithdale VOR (FAF) inbound, and descent to landing minimums is commenced. The aviator should be certain that he has received positive indication of VOR station passage (FAF) before he descends below the intermediate approach segment altitude.

Section II. FEEDER ROUTES/STANDARD TERMINAL ARRIVAL ROUTES (STARS)

195 DEFINITION AND PURPOSE

The terms "feeder route" (sometimes referred to as terminal routing) and "STARs" refer to procedures whereby an aircraft departs one enroute facility or fix and proceeds along a specified course to a nearby initial approach facility or fix. Figure 19-4 shows three facilities in a terminal area: Robinsville (RBN), Brown (BRO), and Smithdale (SMI), and an intersection (GEORGE). Two of these (RBN and BRO) are not suitably located to serve as approach aids; the other (SMI) is located to provide approach service to the airport. Air traffic arriving at RBN may make a straight-in approach (para 19-3), whereas aircraft arriving over BRO or GEORGE intersection would use the published feeder routes to SMI and make a procedure turn (para 19-4).

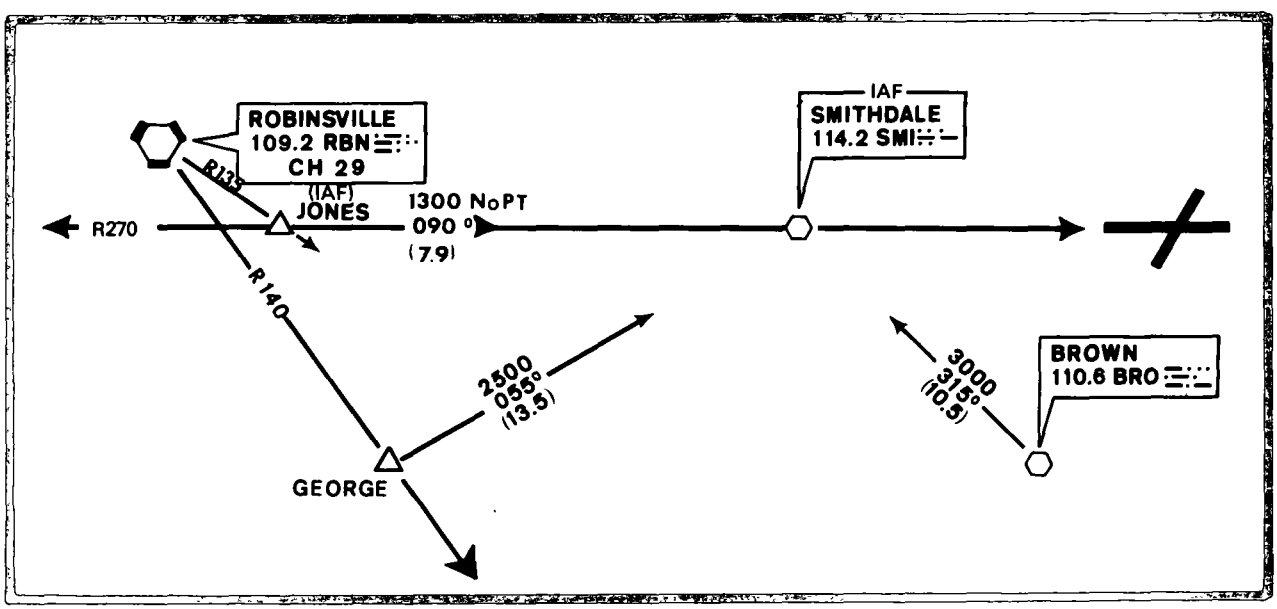


Figure 19-4. Three facilities in a terminal area.

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a. *Feeder Routes.* Information on course, distance, and minimum altitude, which is necessary for the aviator to execute a feeder route, is published on instrument approach charts. Figure 19-4 shows an area with published feeder routes from a VOR facility and an intersection to the SMI VOR approach facility. In each case, the information published for the feeder route consists of—

(1) Course, with the magnetic direction printed and indicated with an arrow.

(2) Distance, shown to the nearest tenth of a mile.

(3) Minimum authorized altitude, which is based upon a standard obstruction clearance of 1,000 feet above obstacles within 4 nautical miles of the feeder course. This same format is used to show course, distance, and minimum altitude for initial and intermediate approach segments with the notation "NO PT" used to indicate that a procedure turn would not be used. (See paragraph 19-3.)

b. *Standard Terminal Arrival Route.* A standard terminal arrival route is an air traffic control coded instrument flight rules (IFR) arrival route established for application to arriving IFR aircraft destined for certain airports. The flight information publication (FLIP) includes a book of STARs for the airports. A STAR will be included in the flight plan if the aviator plans to use one upon arrival at his destination or at any intermediate point where an instrument approach will be made. STARs may have published feeder routes which indicate courses and distances from one or more enroute navigation facilities to the navigational facility or fix from which the STAR begins.

[redacted]

A feeder route or STAR is executed in accordance with the ATC clearance. Arriving aircraft are usually cleared to the initial approach fix (IAF) or to a fix on the enroute structure. Routing or a STAR will be named in the clearance. Certain of these fixes on the enroute structure will have designated feeder routes or STARs to the initial approach fix. If there is to be a delay for the approach, ATC will issue holding instructions. If there is to be no delay for the approach, ATC will issue clearance for an approach prior to the aircraft reaching the fix. The aviator will then execute the published feeder route or STAR (if a STAR has been assigned) to the initial approach fix using the published altitude(s) as desired (unless an altitude restriction or other altitudes had been assigned in the approach clearance) and execute the approach. If there has been no STAR or published feeder route to the IAF, the controller should have issued routing and assigned an altitude to the IAF along with the approach clearance.

Section III. PROCEDURE TURNS

19-8. PURPOSE

A *procedure turn* is a maneuver which allows the aviator to—

a. Reverse flight direction.

b. Descend from initial approach altitude or last assigned altitude to a specified procedure turn altitude from which descent for final approach is begun.

c. Intercept the inbound course at a sufficient distance away from the approach fix to aline the aircraft for the final approach.

19-9. TYPICAL PATTERNS

Typical procedure turn flight patterns are illustrated in (A) and (B) of figure 19-5. A description is given for each illustration ("a" and "b" below).

a. *45° Turn From Nonprocedure Turn Side ((A), fig 19-5).*

(1) In this situation the aircraft flies on the outbound course or parallel to the course on the nonprocedure turn side.

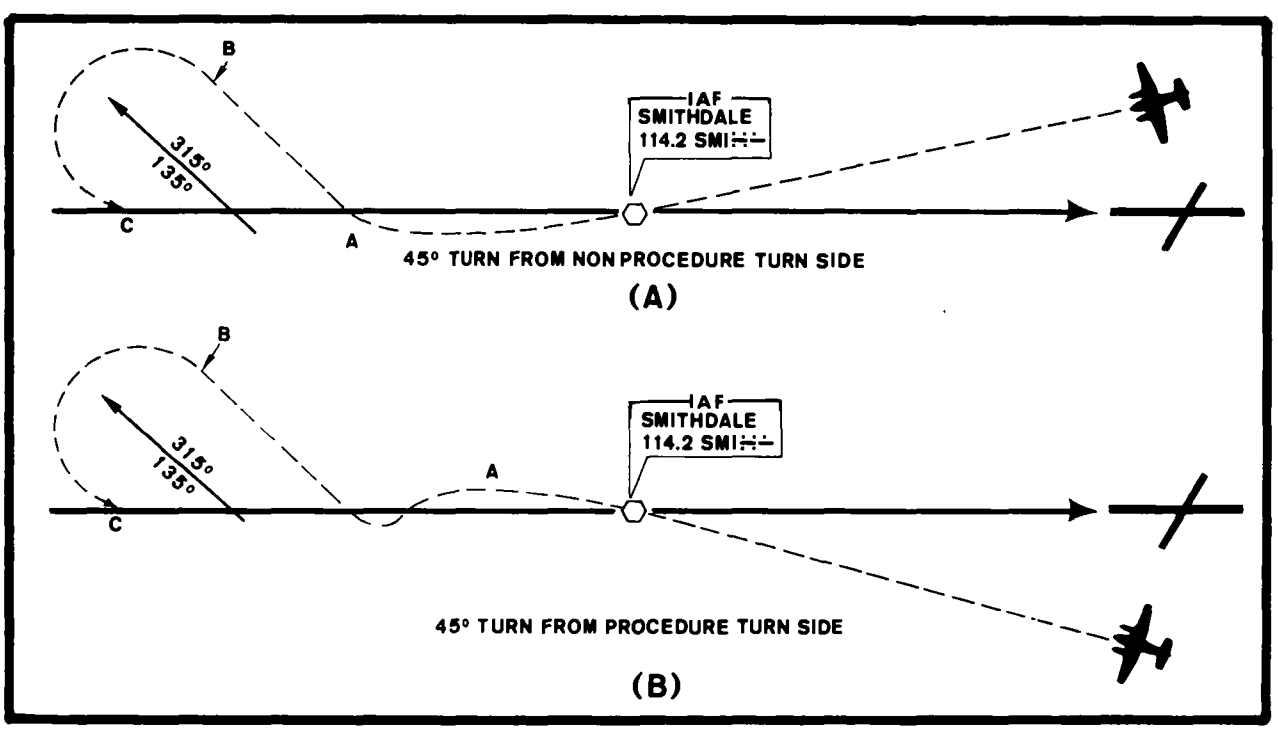


Figure 19-5. 45° turns.

(2) At point A the aircraft turns right to the procedure turn heading published on the approach chart, 315°. The aircraft then flies 40 seconds after crossing the approach course. If tracking outbound on the approach course, timing begins when the aviator starts the turn to the procedure turn heading. The aviator may adjust the time to compensate for known headwinds or tailwinds.

(3) At point B the aircraft turns left to intercept the approach course at point C and flies inbound to the final approach fix.

b. *45° Turn From Procedure Turn Side ((B), fig 19-5).*

(1) In this situation the aircraft flies outbound to point A north of the approach course.

(2) At point A the aircraft turns left to intercept the approach course. After intercepting the approach course, the aircraft turns right to the procedure turn heading published on the approach chart, 315°. The aircraft then continues the procedure as discussed in "a" above.

c. *Teardrop Turn.* A teardrop turn (fig 19-6) may be executed in lieu of the 45-degree type procedure turn if the aircraft heading at the time of crossing the approach facility is conveniently alined with a teardrop course.

> *Note.* **All of the above ("a," "b," and "c") applies to a procedure turn illustrated in figures 19-6 and 19-9. If a teardrop pattern is shown in an approach procedure, the teardrop pattern will be flown.**

(1) Upon arrival over the approach fix, the aviator follows a course outbound

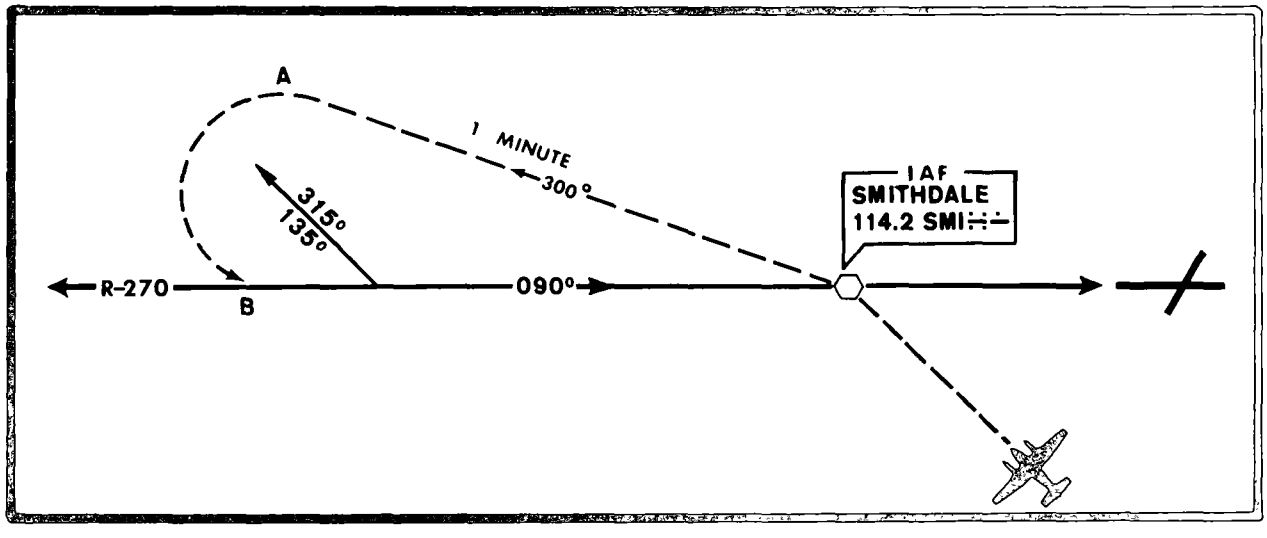


Figure 19-6. Teardrop turn.

not to exceed 30° from the reciprocal of the approach course and on the depicted procedure turn side.

(2) At the end of 1 minute (point A), the aviator turns inbound to intercept the approach course at point B. The timing for the teardrop begins over the approach fix or wings level outbound, whichever occurs last.

19-10. PROCEDURE TURN AREA

a. The limiting distance for procedure turns is published on the profile view of approach charts ((B), fig 19-3). It is normally 10 nautical miles. Deviations from normal will be clearly depicted on the approach charts.

b. In flying outbound from the approach fix to execute the procedure turn, the aviator normally flies a minimum of 1 minute. This outbound leg may be extended, if necessary, to lose additional altitude or compensate for adverse wind effects. However, in no event may the distance outbound from the station exceed that published on the approach chart.

19-11. OBSTRUCTION CLEARANCE—MINIMUM ALTITUDE

The procedure turn altitude is the minimum altitude that can be flown until intercepting the inbound course on approach. The published procedure turn altitude will provide a minimum of 1,000 feet of clearance in the maneuver area. In flying outbound from the approach fix, the aviator normally descends from the route segment altitude (i.e., airway or feeder) to the procedure turn altitude. This descent may vary between several thousand feet and a few hundred feet—or there may be no descent if the feeder route altitude is the same as the procedure turn altitude. The rate of descent is a matter of aviator judgment; however, it should not exceed a maximum safe rate at which the aviator has complete control of the aircraft. A descent rate of 500 feet per minute is recommended for the last 1,000 feet of altitude change. If the aircraft has not arrived at the minimum procedure turn altitude at the time the turn starts, the descent is continued during the turn until the minimum altitude is reached. If the altitude over the initial approach fix is unusually high, it may be necessary to lose the excessive altitude in a holding pattern.

19-12. THE 45-DEGREE PROCEDURE TURN

The procedure turn is made at the standard rate of 3° per second. This rate of turn may be increased or decreased, but not to exceed 30° bank, to allow the aircraft to roll out on the desired track. In aircraft equipped with an integrated flight system which uses a steering pointer, the turn is executed with a centered steering pointer (approximately a 25° bank angle).

a. In executing the 45-degree procedure turn, the aviator will normally fly for 40

seconds from the approach course on the procedure turn heading. This timing is calculated so that the subsequent turn to the inbound course will be completed when the final approach course is intercepted. However, the 40 seconds flying time must be adjusted if known crosswinds exist. Figure 19-7 illustrates the results when time adjustment are not made. During the turn inbound, the aviator must monitor the navigation instruments to see if the turn will result in an interception of the final approach course. When it becomes obvious that it will not, the rate of turn should be adjusted by increasing or decreasing the bank angle. If this action does not line the aircraft with the approach course, the turn should be stopped or continued depending on the position of the aircraft at a 45-degree intercept heading to the inbound course. When the aircraft's position begins to aline with the inbound course, the turn should be continued and appropriate wind drift correction applied.

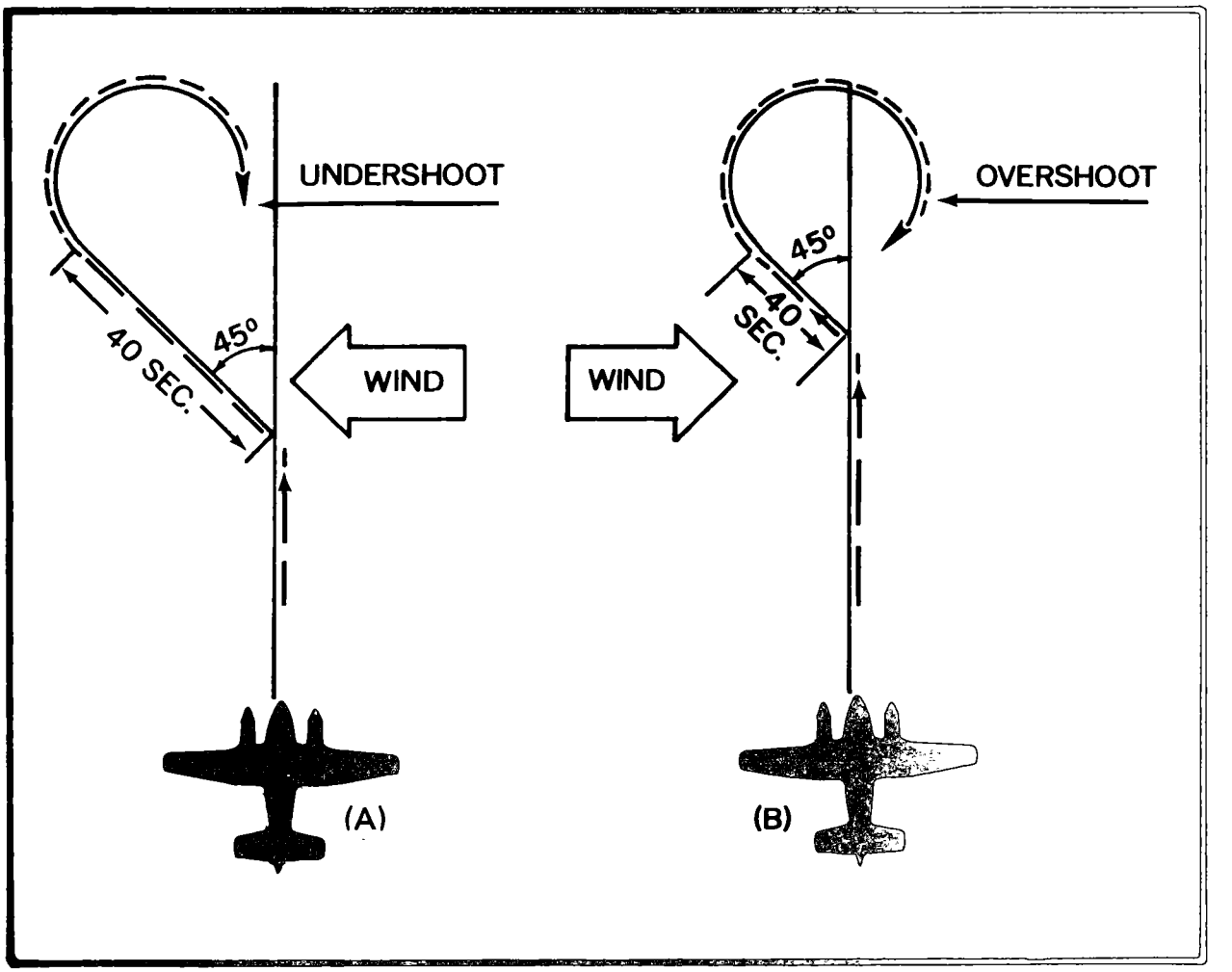


Figure 19-7. Improper procedure turn patterns caused by wind effects.

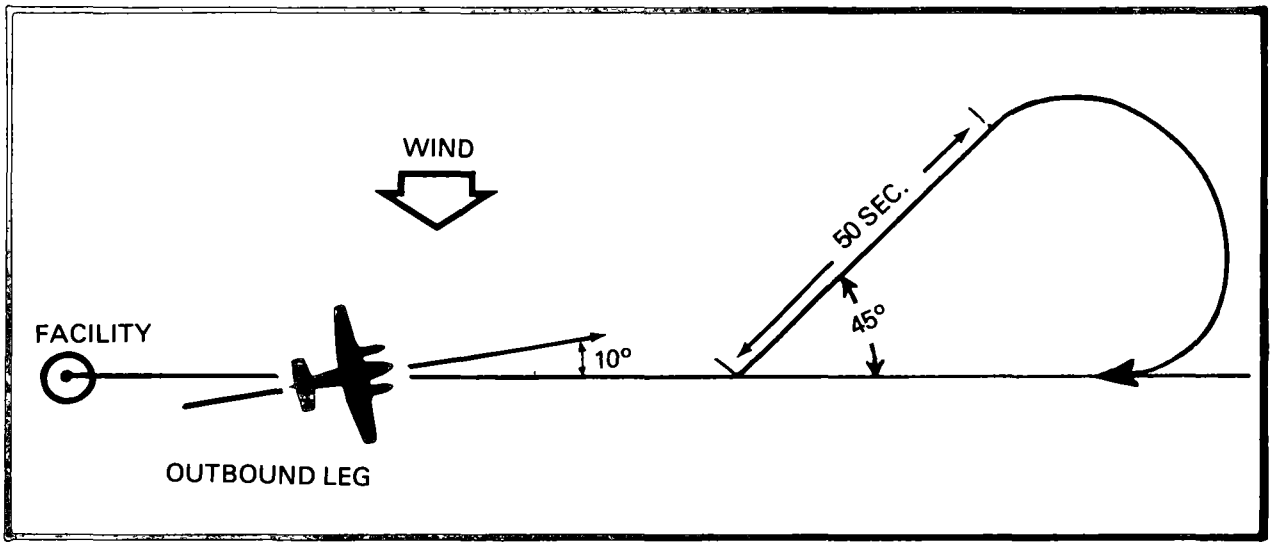


Figure 19-8. Adjusting procedure turn for wind effects.

b. Adjustment of the 40 seconds flying time is based upon the known or estimated drift correction required to fly the track outbound. An allowance of 1 second for each degree of drift correction used on the outbound leg should be applied to the 40 seconds flown on the leg of the procedure turn. Figure 19-8 shows the aircraft holding a 10-degree drift correction flying outbound for the procedure turn. After turning left 45°, the aircraft will be headed into the wind and will fly for 50 seconds.

19-13. MISSED APPROACHES

If the instrument approach and landing cannot be completed successfully, the aviator executes a *missed approach* procedure. This procedure is published on the approach chart and normally is supplemented by further instructions and clearances from the controller.

a. *Procedure.* The typical procedure normally directs the aircraft to proceed on a specified course to or from a designated facility, and to climb to a specified minimum altitude. Figure 19-9 shows plan and profile views of an instrument approach procedure, with the missed approach procedure printed within the profile view. The aircraft is making the final approach on the 290-degree radial from the facility and is unable to complete the landing. The aviator begins climbing to an altitude of 1,800 feet, indicated on the altimeter (1,582 feet above the airport), on a direct course to the Mobile Semmes VORTAC with intent of holding. The procedure is based upon the use of the Mobile Semmes VORTAC; the missed approach altitude guarantees adequate obstacle clearance provided the aviator begins to climb at the missed approach point and follows the published procedure.

b. *Report.* The aviator must report a missed approach and include the reason

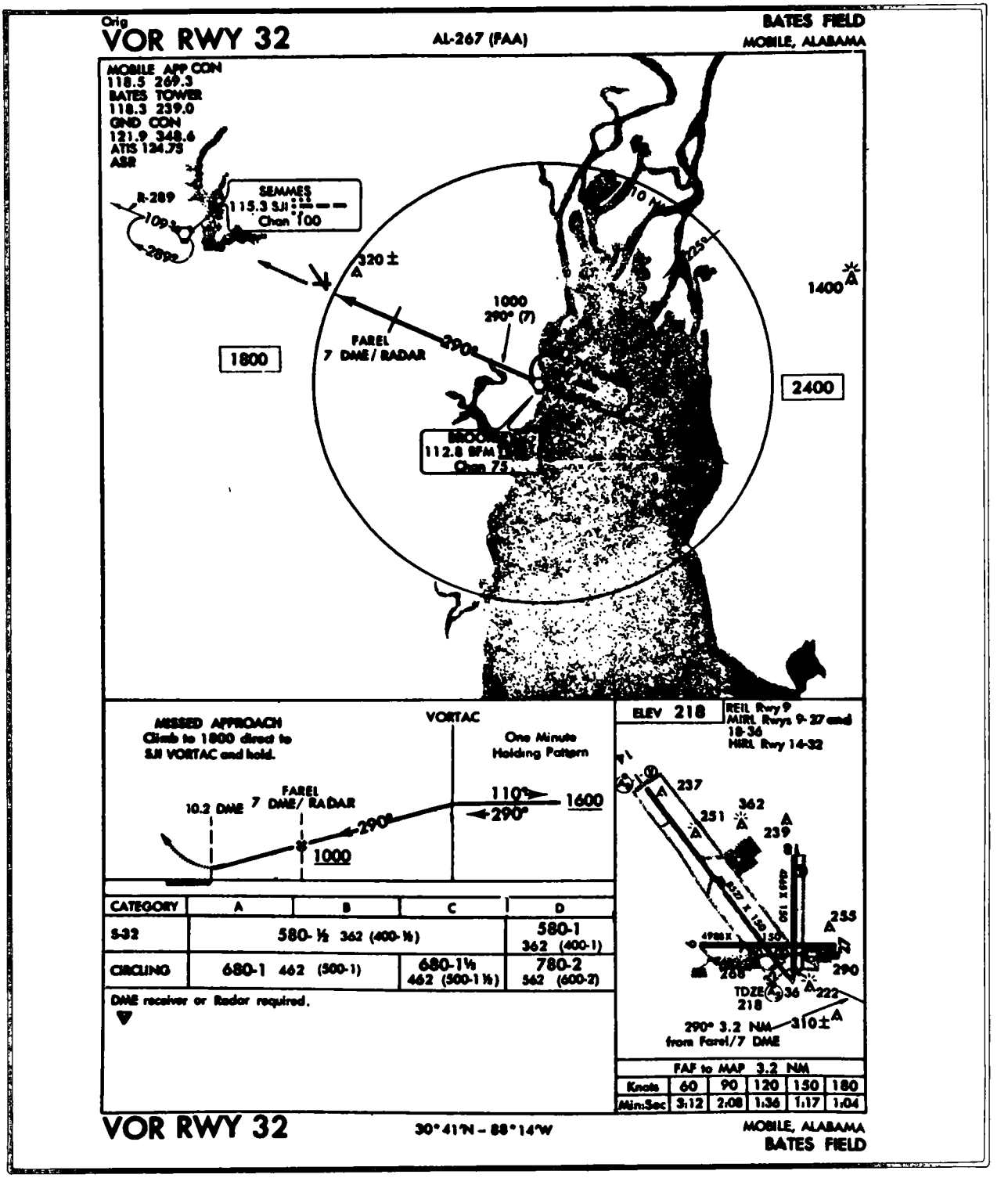


Figure 19-9. Plan and profile views of an instrument approach procedure.

(unless initiated by ATC) to the controller as soon as practical after he starts the procedure. He reports the missed approach and makes a specific request. The aviator may request clearance to execute another approach (if feasible), or he may request clearance and file a flight plan to an alternate airport.

Note: Obstacle clearance in the missed approach area is based on a 40:1 surface requiring a climb of 152 feet/NM. (Copter only procedures, use a 20:1 surface which requires 304 feet/NM.)

Section IV. HOLDING

Because of heavy traffic conditions en route or at busy air terminals, air traffic controllers occasionally instruct aviators to *hold. Holding* is the procedure used to delay an aircraft at a definite position and assigned altitude. In some instances the aviator is directed to climb or descend to a newly assigned altitude in the holding pattern.

The *standard* holding pattern consists of *right* turns (fig 19-10), the *nonstandard* holding pattern of *left* turns.

a. The initial outbound leg of a holding pattern at or below 14,000 feet mean sea

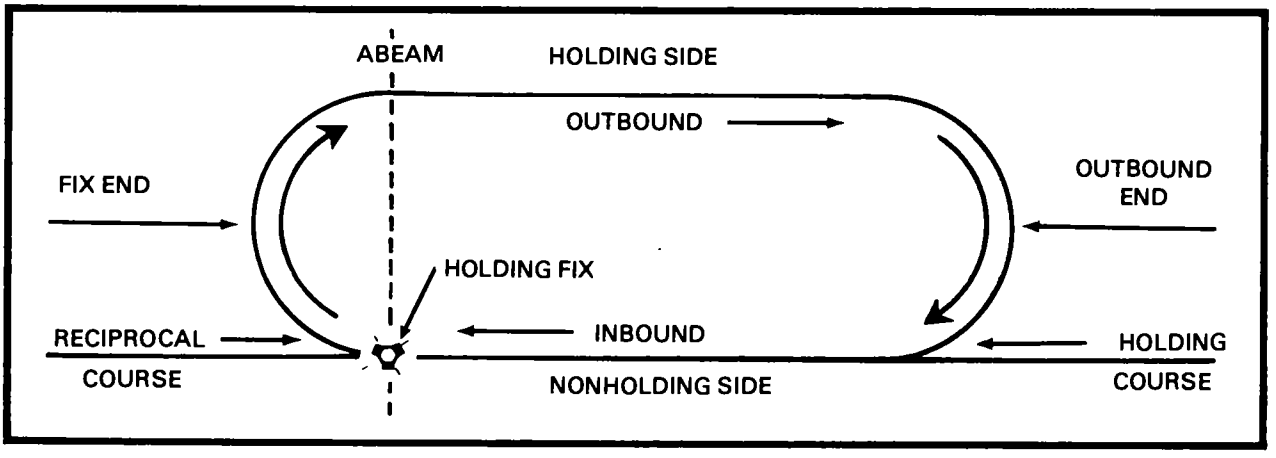


Figure 19-10. Standard holding pattern.

level (MSL) is flown for 1 minute. Above 14,000 feet MSL, the leg is flown for 1 1/2 minutes. This applies unless otherwise specified in the approach chart or in the ATC clearance.

b. Subsequent outbound legs are adjusted (depending on the wind) so that the inbound leg is 1 minute at and below 14,000 feet MSL and 1 1/2 minutes above 14,000 feet MSL. *For example:*

(1) A helicopter flying a true airspeed of 75 knots experiences a 30-knot headwind on the outbound leg and a 30-knot tailwind on the inbound leg. The following tabular data shows the comparative times flown on the outbound and inbound legs to compensate for this wind (no allowance is made for drift during the inbound turn):

Outbound Time	Inbound Time
1 minute	26 seconds
1 minute and 20 seconds	34.5 seconds
1 minute and 40 seconds	43 seconds
2 minutes	51.5 seconds
3 minutes	1 minute and 17 seconds

(2) In this example, therefore, the aviator must fly approximately 2 minutes and 20 seconds on the outbound leg to achieve the desired 1-minute flying time on the inbound leg.

c. Outbound timing (fig 19-11) begins over or abeam the holding station, whichever occurs later. The position abeam the station can be determined by a change of the TO-FROM indicator or by setting the course selector to a radial 90° from the approach course. When the needle centers, the aircraft is at the abeam position. The radio magnetic indicator (RMI) is used to determine the abeam position for both VHF omnidirectional range (VOR) and automatic direction finder (ADF) holding. When the appropriate bearing pointer points to a heading 90° to the holding course, the aircraft is at the abeam position. During intersection holding, outbound timing is started when the aircraft has completed its outbound turn and is wings level on the outbound heading. Outbound time will be adjusted to achieve the desired inbound time.

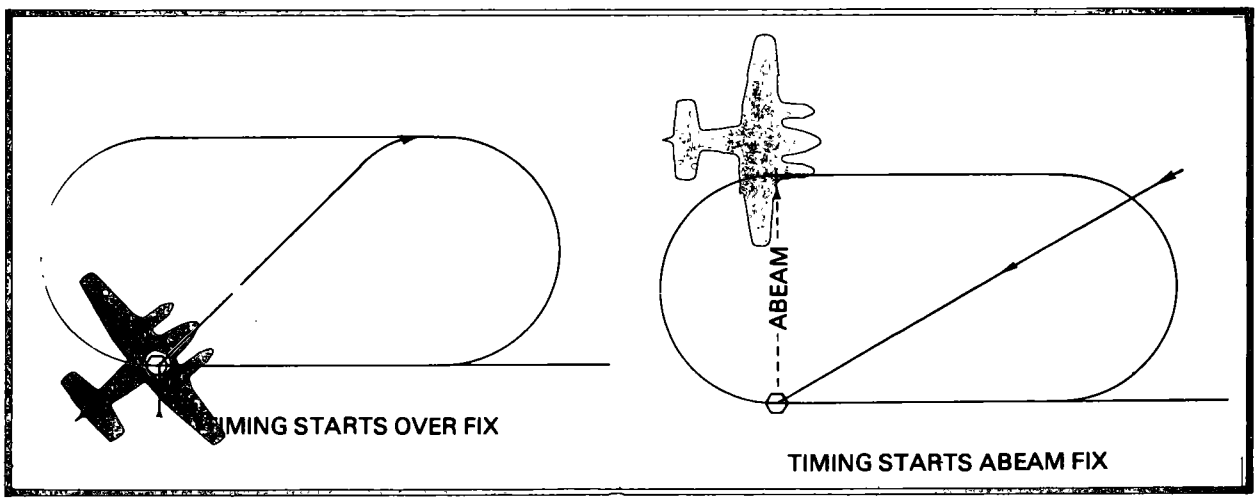


Figure 19-11. Outbound timing.

d. The procedure for determining the abeam position as discussed in "c" above will not be affected by the aircraft heading. Outbound timing should begin when any one of the indicators identifies the abeam position regardless of the outbound heading.

[redacted]

Maximum indicated airspeed (IAS) allowed for holding is 175 knots for all propeller-driven aircraft and helicopters. Exception: Helicopters using holding patterns depicted on helicopter (COPTER) instrument approaches (FLIP) will fly 90 knots maximum indicated airspeed. Different speeds are allowed for civil and military turbojet aircraft, depending on holding altitude and aircraft category, as listed in current navigation publications. Aircraft operating en route at normal cruise airspeeds higher than the maximum authorized for holding are required to reduce airspeed 3 minutes or less from the holding fix.

[redacted]

Make all turns during entry and while holding at: (1) 3° per second, or (2) not to exceed 30° bank angle, or (3) 25° bank angle, provided a flight director system is used.

19-19. HOLDING PATTERN ENTRY

a. *Aviator Action.*

(1) Cross holding fix initially at or below maximum holding airspeed. If required, effect speed reduction 3 minutes or less from the holding fix.

(2) Compensate for known effect wind, except when turning.

(3) Determine entry turn from aircraft heading upon arrival at the holding fix.

b. *Standard Holding Pattern Entry (fig 19-12).*

(1) Refer to letters on figure 19-12 in applying the following instructions:

(a) Parallel procedure—parallel holding course, turn left, and return to holding fix or intercept holding course.

(b) Teardrop procedure—proceed on outbound track of 30° (or less) to holding course; turn right to intercept holding course.

(c) Direct entry procedure—turn right and fly the pattern.

(2) Distance measuring equipment (DME) holding is subject to the same entry and holding procedures as in "(a)" and "(b)" above except that distances (nautical miles) are used in place of time values. The outbound course of a DME holding pattern is called the outbound leg of the pattern. The length of the

outbound leg will be specified in the procedure chart or by the controller. The end of the outbound leg is determined by the appropriate odometer reading. For example, see figure 19-13. When the inbound course is toward the navigational aid (NAVAID) and the fix distance is 10 NM, and the leg length is 5 NM, then the end of the outbound leg will be reached when the odometer reads 15 NM. For example, see Figure 19-13. When the inbound course is away from the NAVAID and the fix distance is 28 NM and the leg length is 8 NM, then the end of the outbound leg will be reached when the odometer reads 20 NM.

(3) Nonstandard holding pattern entry. The fix end and outbound end turns are made to the left. Entry procedures to a nonstandard pattern are oriented in relation to the 70-degree line on the holding side just as in the standard pattern.

19-20. DEPARTING THE HOLDING PATTERN

When cleared by the controller to leave the holding fix, the aviator normally departs the pattern from over the fix. An exception to this occurs when the controller

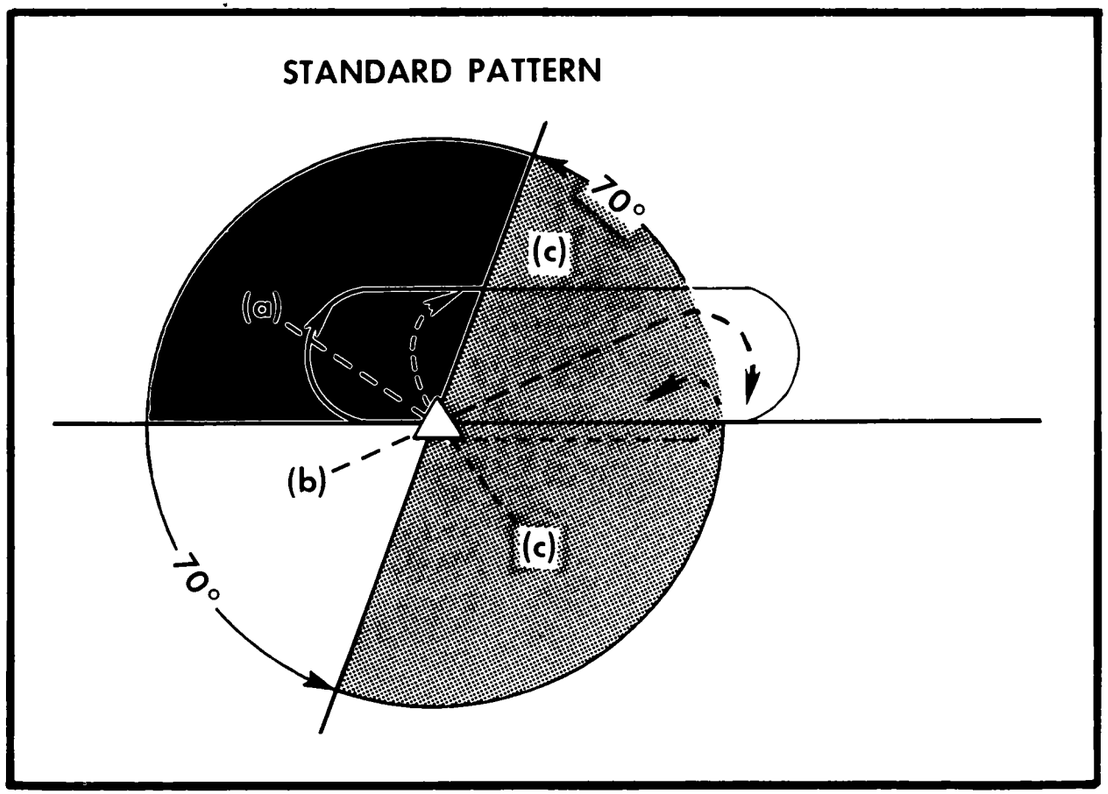
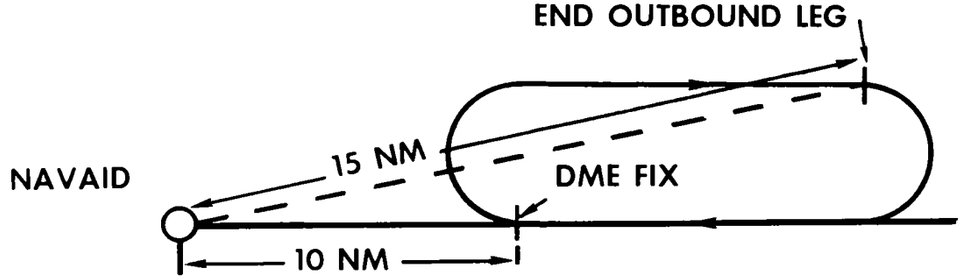


Figure 19-12. Holding pattern entry.



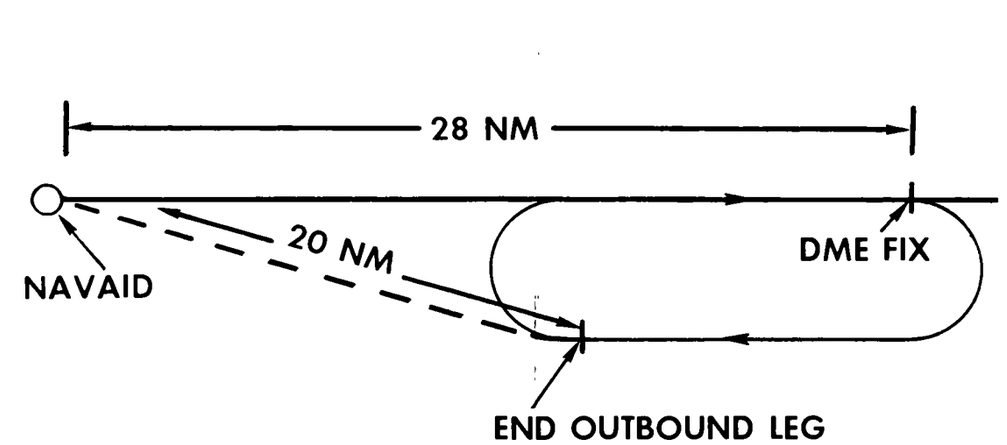


Figure 19-13. DME holding.

specifically states "cleared from your present position ..." If the controller has specified a departure time, the aviator must adjust the holding pattern so that the aircraft is over the holding fix ready to depart at the specified time. If an aircraft is holding on the published final approach course at an approach fix and receives clearance for the approach, the aviator normally begins the final approach from the holding pattern without executing the conventional procedure turn.

Note. At some locations, beginning the final approach from the holding pattern may be prohibited by notes published on the approach chart. When this occurs a standard procedure turn will be flown.

19-21. [illegible]

a. The aviator will compensate for known effect of wind, except while turning. If no attempt is made to correct for adverse effects of crosswinds while holding, the turn inbound will either overshoot or undershoot the holding course depending on the direction of the wind (fig 19-14).

b. If the same amount of drift correction is flown for both inbound and outbound legs (but applied in opposite directions), the outbound leg will parallel the inbound leg; however, the turns will still be wide or tight, respectively. Since

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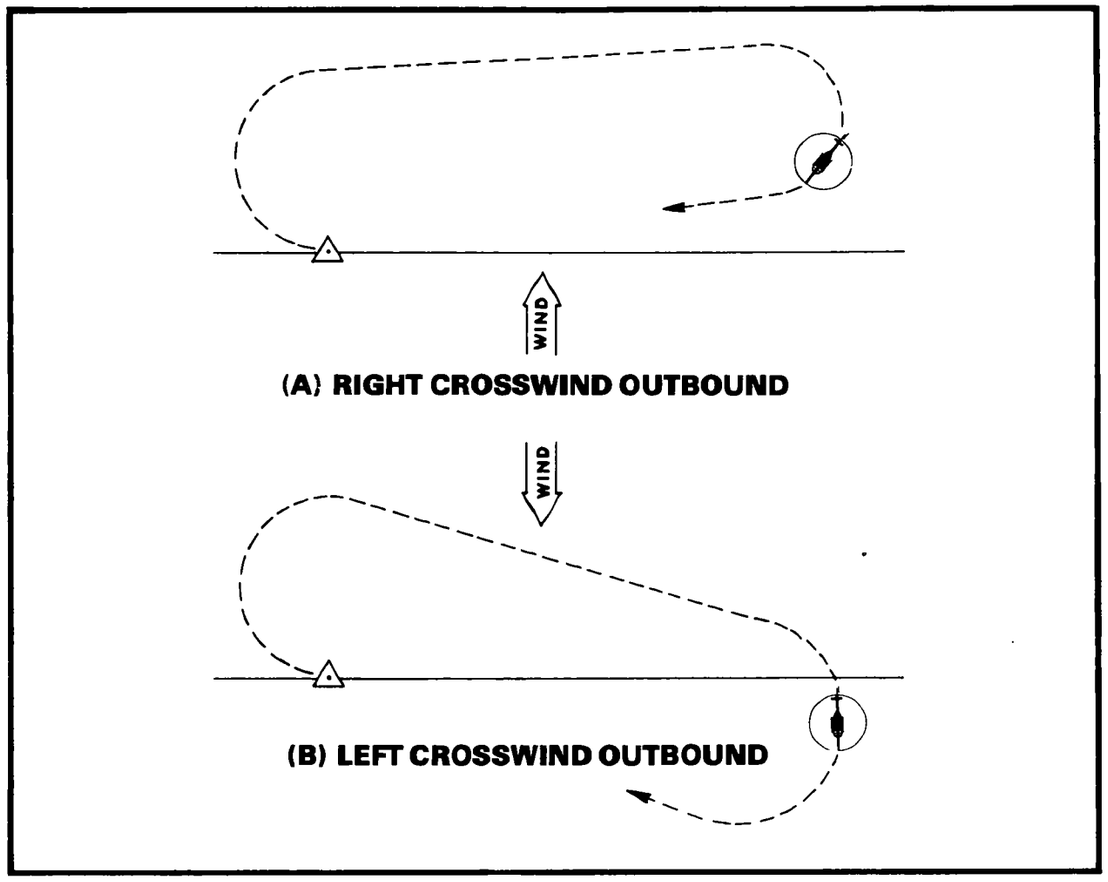

Figure 19-14. Wind effect on holding pattern flight.

the aviator has little control over the aircraft's track while turning, he must adjust the track of the outbound leg to avoid turning short of or overshooting the holding course due to effects of wind drift.

c. For holding pattern drift correction—

(1) Determine the correction necessary to maintain the track inbound.

(2) While flying the outbound leg, double the inbound correction and apply it in the opposite direction; or if the inbound correction is over 10°, use an outbound correction of 10° plus the inbound correction.

Note. This guide must be adjusted to fit each situation. Analysis of the initial inbound turn (overshooting or

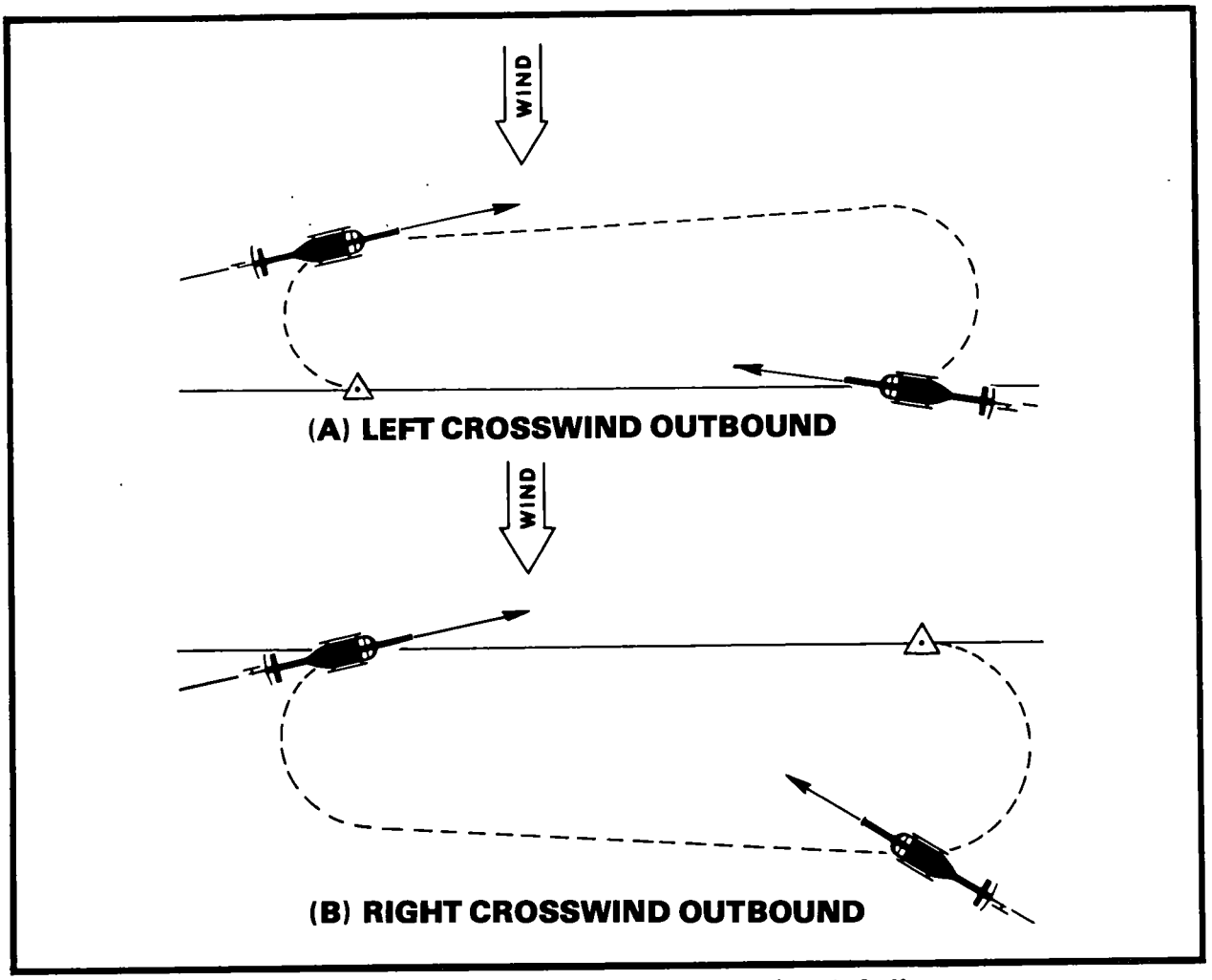

Figure 19-15. Adjusting holding pattern for wind effect.

undershooting) should be used as a basis for a subsequent adjustment.

d. Two examples of applied drift correction are—

(1) In (A) of figure 19-15, the inbound correction is 5° right; therefore, the correction used outbound is 10° left.

(2) In (B) of figure 19-15, the inbound correction is 15° left; therefore, the correction used outbound is 25° right.

1922. HOLDING CLEARANCES AND REPORTS

a. When delivering an ATC clearance for holding at a fix with a depicted holding pattern, the controller gives the following information in the order shown:

(1) Direction to hold from the holding fix.

(2) Name of the holding fix.

(3) Time to expect further clearance (EFC) or time to expect approach clearance (EAC).

b. If the holding pattern is not depicted, the controller issues general or detailed holding instructions. General holding instructions contain the following information in the order shown.

(1) Direction to hold from the holding fix.

(2) Name of the holding fix.

(3) Radial, course, bearing, airway, or jet route which constitutes the holding course.

(4) Outbound leg length in nautical miles if DME is to be used.

(5) Direction of holding pattern turns, if left turns are to be made.

(6) Time to expect further clearance or expect approach clearance.

c. Detailed holding instructions contain the same items as for general holding above but always specify the leg length in minutes, nautical miles area navigation (RNAV), or nautical miles DME, and direction of holding pattern turns.

d. Typical clearances are:

(1) "Cleared to AJAX VOR, hold south, expect approach clearance at 1930" ((A), fig 19-16).

(2) "Hold south of the AJAX VOR on the 180-degree radial; expect approach clearance at 1930" ((B), fig 19-16).

(3) "Hold northeast of Cliff intersection on Victor 21, left turns, expect further clearance at 2050" ((C), fig 19-16).

e. If not in radar contact, aviators are required to report the time and altitude reaching a holding fix and when departing the holding fix. These reports are not required if in radar contact. In all cases the aviator will report when departing a holding fix.

Stacking is the procedure when two or more aircraft are holding, one above the other, at the same fix. As the lower aircraft leaves the stack to complete its approach, the aircraft above it is cleared to the next lower holding altitude. This clearance is given after the aviator of the approaching aircraft has reported that he is vacating his altitude and is leaving the radio facility inbound. The second aircraft is cleared for an approach when the first aircraft is sighted by the tower and when the tower considers that a normal, safe landing will be accomplished. The length of time an aircraft is required to hold in a stack depends upon the time required by the air-

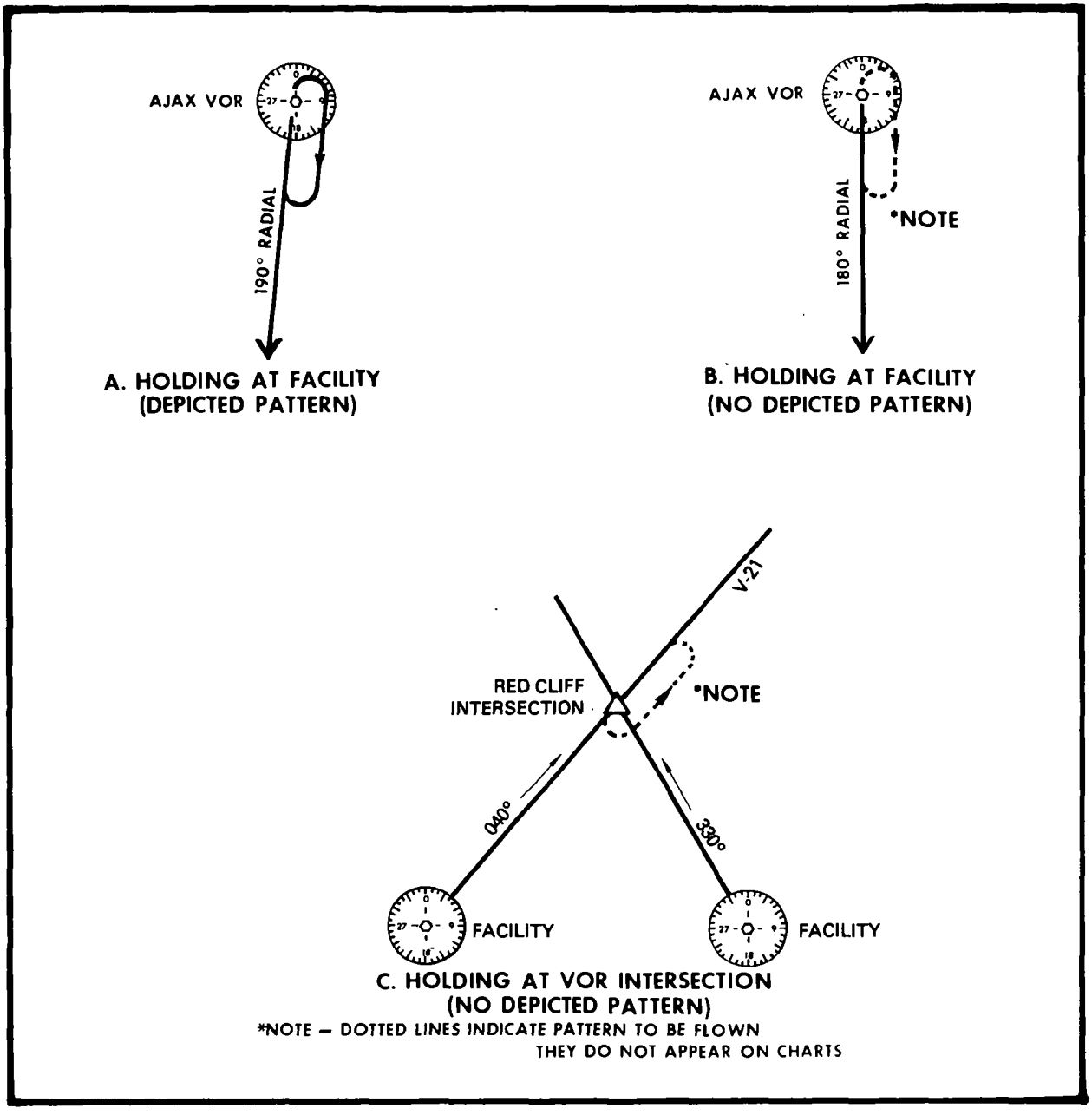

Figure 19-16. Holding patterns flown for typical clearances.

craft in the lower positions to land. Since the delay may be of considerable duration, the aviator should fly at an airspeed and power setting which will provide fuel economy but still permit adequate aircraft control.

[redacted] APPROACH

Even the aviator with vast instrument flying experience will make a safer instrument approach if he uses a copilot to assist him. Before the flight the copilot should be briefed and made to understand the duties he will be expected to perform. This is especially important on the most critical phase of an instrument flight—the instrument approach and landing. In addition to any other duties assigned the copilot, the following duties are deemed important to the execution of a safe instrument approach and landing. The copilot should:

a. Monitor all engine instruments and warning lights.

b. Be sure that the correct approach chart is being used.

c. Know at all times the position of the aircraft in the approach pattern.

d. Crosscheck flight instruments and radio navigation instruments for malfunction.

e. Check that altimeters are set at the correct barometric pressure.

f. Take time to check all altimeter indications. (The pilot may misread the altimeter.)

g. Verify all fixes that are determined during the approach.

h. Keep close watch on the altimeter on the final approach segment and notify the pilot when he is approaching 100 feet above the DH or MDA (whichever applies to the approach) and when he is approaching DH or MDA.

i. Watch for the approach lights or runway to come into view. He will not inform the pilot that they are in view until positive that they will remain in view and the approach can be continued visually to a landing.

j. Be prepared to take the aircraft controls and make the visual approach and landing if requested by the pilot.

CHAPTER 20

VHF OMNIDIRECTIONAL RANGE (VOR) AND NONDIRECTIONAL BEACON (NDB) APPROACHES

Section I. APPROACH CHARTS

[redacted]

The separate VOR and NDB approach charts published by Federal agencies and private companies contain complete information on current instrument approach procedures at specific airfields. The format of all these charts is basically the same. Therefore, once the aviator has studied one type chart and its legend, he is usually able to use other types effectively.

[redacted] VOR APPROACH CHART

a. *General.* The Cairns Army Airfield (AAF) VOR runway 6 approach chart (fig 20-1) is typical of those found in current navigational publications. Its format and general data presentation are a guide for the aviator. For detailed explanation of approach chart symbols, consult flight information publication (FLIP) instrument approach procedure charts and their legends printed with each volume.

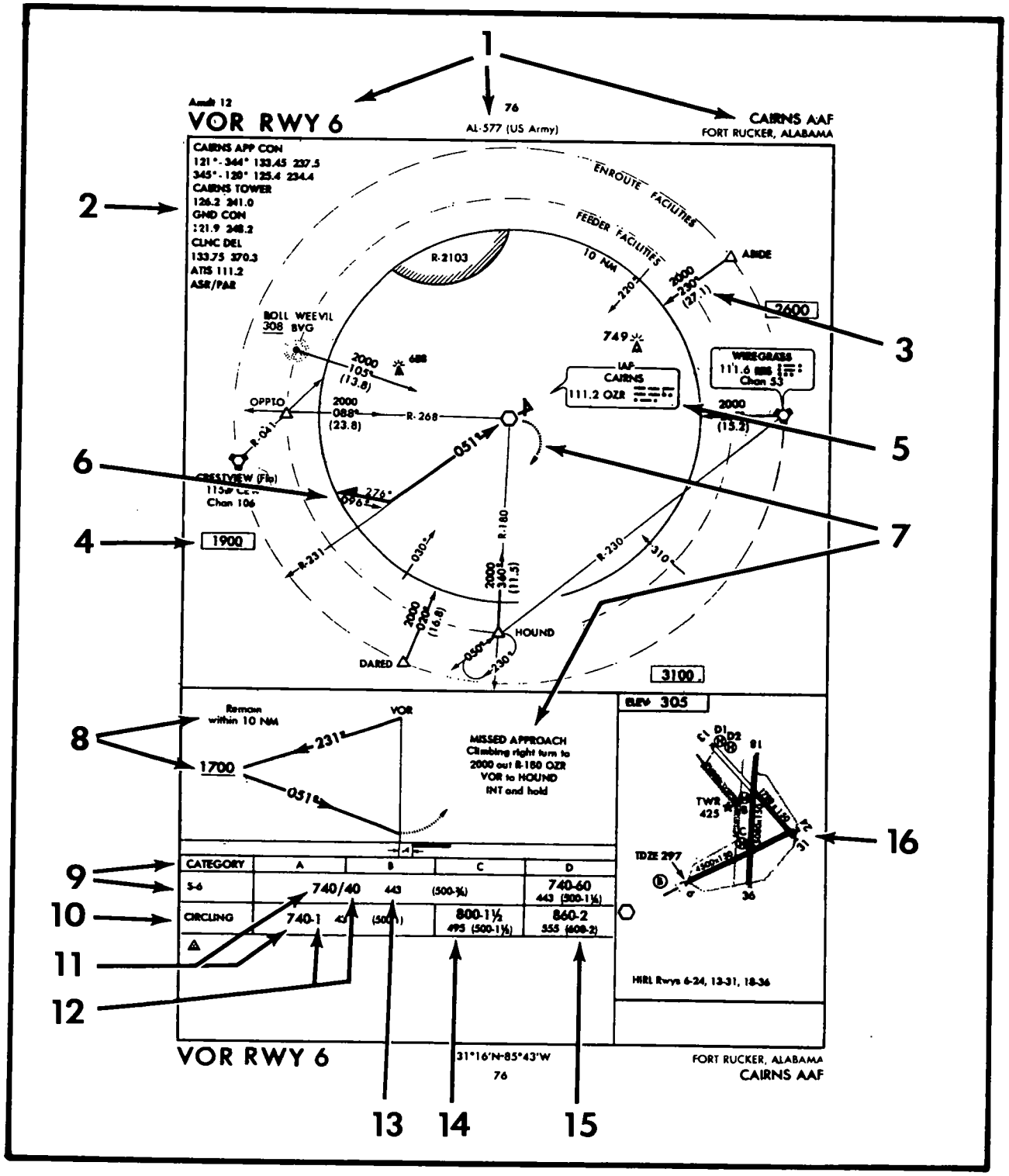

Figure 20-1. Typical VOR approach chart.

b. *Explanatory Data for Figure 20-1.* The following numbered items apply to the same numbers shown on figure 20-1:

(1) Chart title includes type of approach (VOR, NDB, instrument landing system (ILS), localizer (LOC) etc.) and to which runway, and name of airport, city, and state. Charts which include the word "COPTER" in the title are for exclusive use of helicopters.

(2) Communications data includes primary frequencies for approach control, tower, ground control, etc., and type of radar (airport surveillance radar/precision approach radar (ASR/PAR)) or other service available.

(3) Feeder route data from outer fixes includes minimum altitude (2,000 feet), direction (230°), and distance (27.1 nautical miles (NM)).

(4) Minimum sector altitudes within 25 NM.

(5) Approach facility location identification shows frequency, name, identifier, and code. (May contain communication capability restriction legend.)

(6) Procedure track shows direction of procedure turn with 45° off-course bearings.

(7) Missed approach track with description listed in profile.

(8) Procedure turn data: limiting distance (remain within 10 NM) and minimum altitude (1,700 feet).

(9) Straight-in (RWY 6) minima data by aircraft category (aircraft category based on stall speed and maximum gross weight).

(10) Circling minima data by aircraft category.

(11) Minimum descent altitude (MDA) shown in feet above mean sea level (MSL). This is the lowest altitude to which descent is authorized until airport or runway environment is in sight.

Note. **On precision approaches (approaches with glide slope information), this value is referred to as a decision height (DH).**

(12) Visibility values are expressed as runway visual range (RVR), prevailing visibility (PV), or runway visibility (RV). RVR is shown in hundreds of feet; e.g., 24 equals 2,400 feet. PV and RV are shown in statute miles and fractions thereof; e.g., 1 1/2 equals 1 1/2 statute miles.

(13) Height above touchdown (HAT) indicates height of MDA (or DH on precision approaches) above the runway elevation in the touchdown zone (first 3,000 feet) of runway for *straight-in* landings.

(14) Height above airport (HAA) indicates height of MDA above airport elevation for *circling* to land.

(15) Ceiling and visibility value for military use in accordance with current directives.

(16) Airport diagram to show airfield elevation, runway location with dimensions, runway and approach light information, direction and distance from related facility, touchdown zone elevation (TDZE 297 feet), taxiway and helicopter landing areas used in air traffic control, obstruction height, and closed runways.

Section II. TYPICAL VOR APPROACH

20-3. VOR STATION LOCATION

VOR stations used in VOR approaches may be located some distance from the airport as shown in figure 19-9 (called *OFF airport VOR*) or may be located on or near the airport as shown in figure 20-1 (called *ON Airport VOR*). Figures 20-1 and 20-2 are used to illustrate a typical VOR approach procedure.

20-4. [illegible]

An aviator is flying eastbound on V-241 at 5,000 feet with Cairns AAF as his destination (fig 20-2). In compliance with air traffic control (ATC) instructions, he establishes radio contact with Cairns approach control over DARED intersection. Cairns approach control clears him to the Cairns VOR from over HOUND

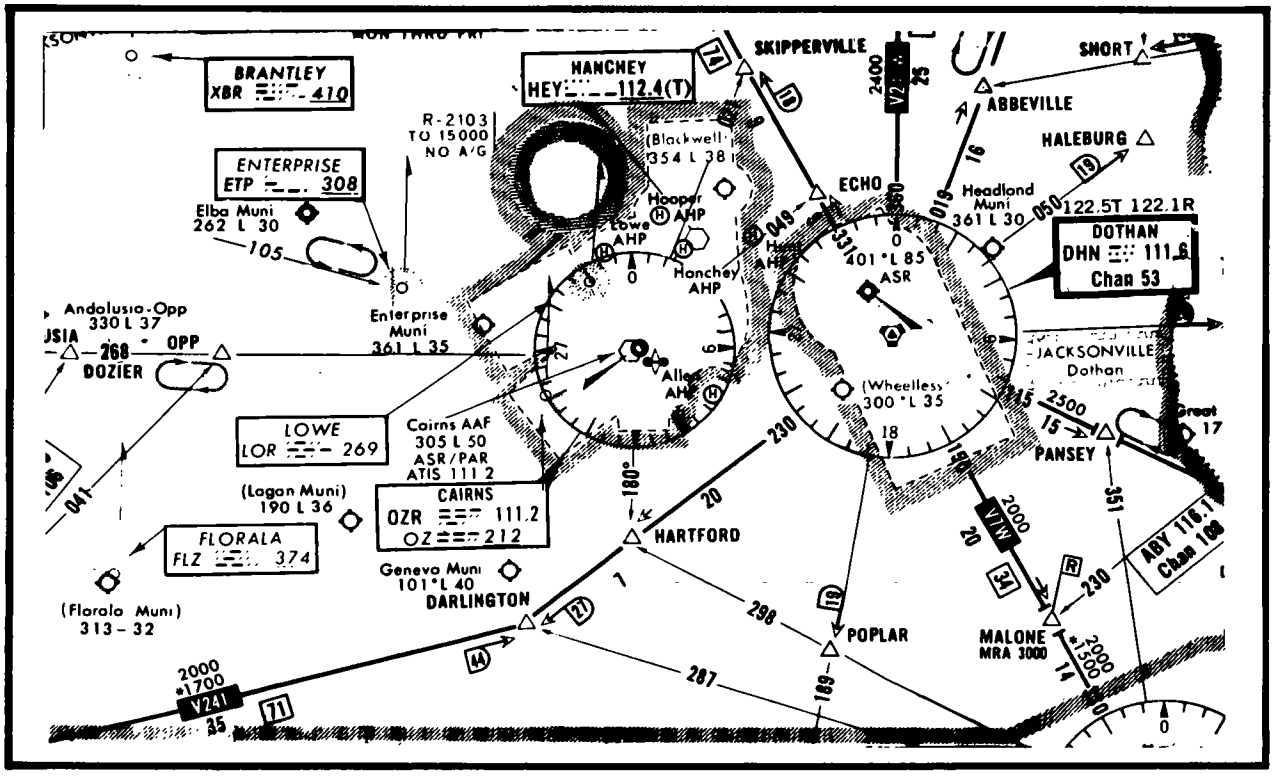

Figure 20-2. Typical enroute chart.

intersection, with clearance to hold southwest of Cairns VOR on the 231° radial left turns. He is cleared to descend and maintain 4,000 feet and given an expected approach clearance time of 1525. Upon arrival at Cairns VOR at 4,000 feet, the aviator—

a. Notes the time.

b. Turns outbound to enter the holding pattern.

c. Reduces airspeed to prescribed holding speed if not done previously.

Note. To comply with maximum holding airspeed, reduction of airspeed should be done when 3 minutes or less from the holding fix.

d. Reports to air traffic control (ATC) if required.

Note. Actions "a" through "c" above are performed almost simultaneously. The report is not made until after station passage.

2d Lt. [illegible]

a. Initial passage of Cairns VOR occurs when the TO-FROM indicator reverses readings (TO to FROM). The aviator then turns outbound to a heading of 231° (fig 20-3) to enter the holding pattern. Use of the course selector and deviation needle to track outbound during the entry procedure

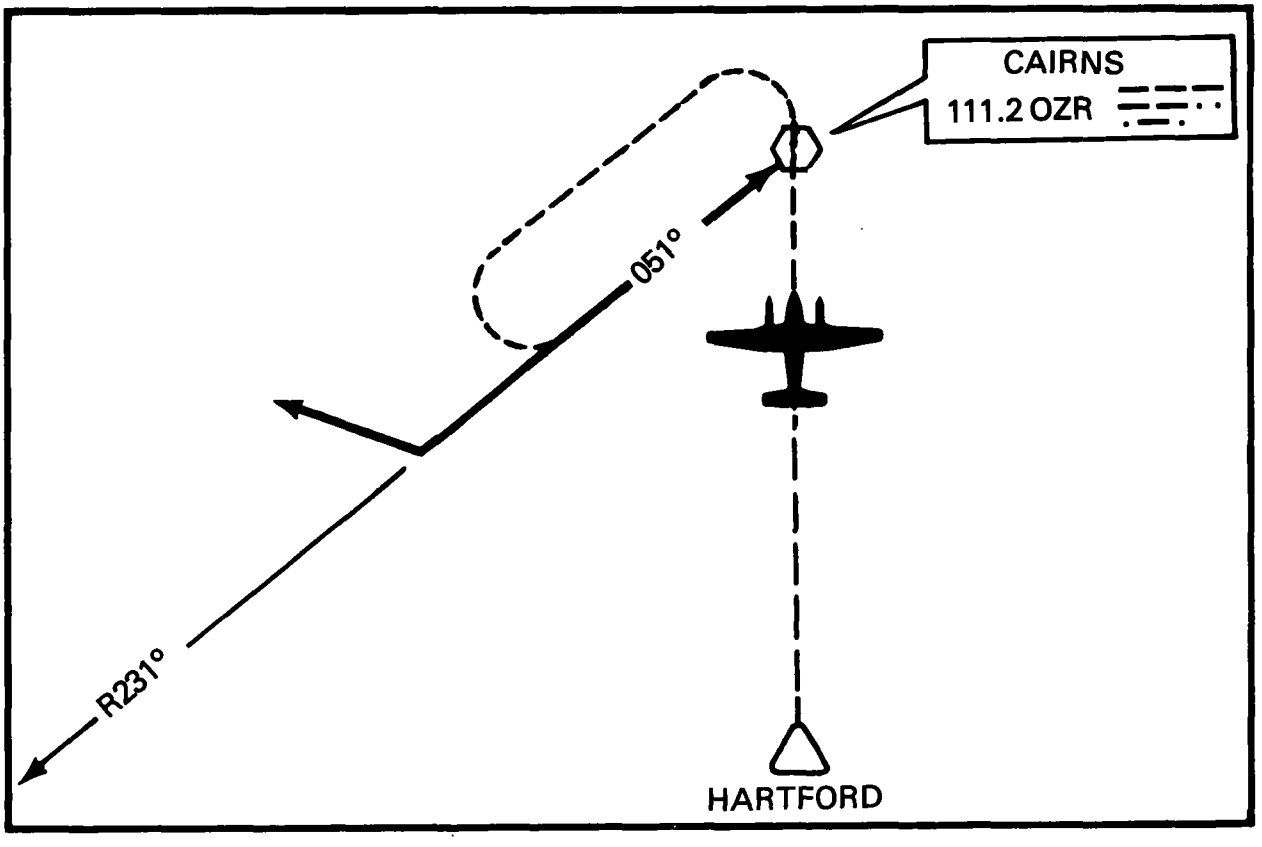

Figure 20-3. Holding pattern entry.

is optional, but this procedure will aid the aviator in orienting himself with respect to the VOR station and to the holding radial. He may either set the course selector on the holding radial outbound or fly a heading outbound with the course selector set for tracking inbound on the holding radial.

b. After flying 1 minute on the outbound heading of the entry leg, the aviator turns left to intercept the holding course inbound (051°, fig 20-3). Prior to turning, the course selector is set on 051° and the TO-FROM indicator reads TO. The aviator should adjust the inbound turn as he monitors the course indicator and/or the radio magnetic indicator (RMI) to intercept the desired inbound course.

c. During the initial inbound leg of the holding course, the aviator should determine (1) the drift correction necessary to remain on the desired track, and (2) the time flown on the inbound leg. It should be noted that the aviator probably won't be able to establish proper drift correction his first time inbound,but should be able to do so on subsequent legs. Subsequent outbound legs of the holding pattern are adjusting so that each inbound leg requires 1 minute. Drift corrections in the holding pattern are discussed in chapter 19.

d. After flying over the VOR facility, the aviator makes a 180-degree turn to the outbound heading of the holding course. Timing for the outbound leg should begin when the aircraft is abeam the station. One accurate method for determining his position abeam the station is by rotating the course selector 90° to fix the aircraft position abeam the station (fig 20-4). This technique permits the aviator to time the outbound leg accurately from a position abeam the station.

(1) *Point A.* During the left turn outbound, the aviator rotates the course selector 90° to the left (reading of 321°), thereby enabling him to fix his position abeam the station. During the turn, the deviation needle deflects full left.

(2) *Point B.* Needle centers abeam the station. Outbound timing begins at this time.

(3) *Point C.* After passing point B, course selector is reset to 051° to intercept the holding course inbound. The needle deflects to the side away from the holding course during the outbound portion of the holding pattern.

(4) *Point D.* Needle centers as aircraft turns inbound and intercepts the holding course.

e. Other methods of accurately determining position abeam the station are set forth in chapter 19.

f. When holding at a fix where methods described in "d" and "e" above cannot be used, the aviator should begin timing the outbound leg immediately after rolling out of the 180-degree standard rate turn.

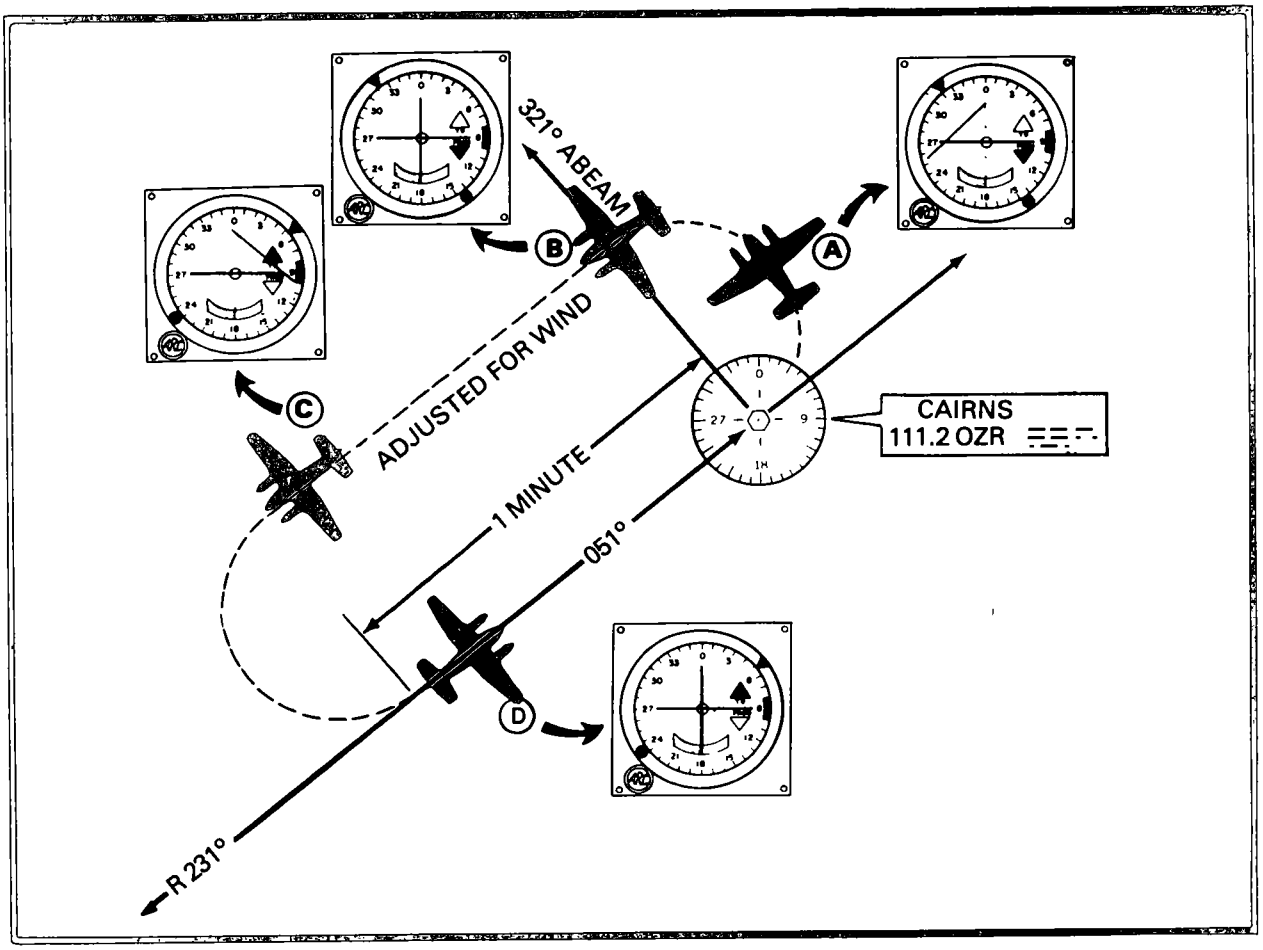

Figure 20-4. Flying a holding pattern.

20-6. DESCENT WHILE HOLDING

a. The aviator is holding at 4,000 feet over Cairns VOR. The approach chart (fig 20-1) shows the minimum procedure turn altitude for the VOR approach to the field as 1,700 feet. As lower air traffic departs the holding pattern, the controller clears the aviator to descend to a lower holding altitude. In this situation, the clearance to 3,000 feet is received. The aviator continues the established holding pattern and establishes a 500-foot-per-minute (fpm) rate of descent. When the aviator reports leaving 4,000 feet, the controller can assign this holding altitude to another aircraft. A 500-foot-per-minute rate of descent should not be exceeded when within 1,000 feet of desired altitude.

b. If the aircraft had been at a higher altitude (e.g., 9,000 feet), and had been cleared to a low altitude (e.g., 3,000 feet), the aviator could have established the

maximum rate of descent at which he could still fully control the aircraft. He could have used this rate to within 1,000 feet above the newly assigned holding altitude; he would then reduce to a rate not to exceed 500 feet per minute for the 1,000 feet of descent.

20-7. THE APPROA[redacted]

a. The aviator has been advised of his expected approach clearance time (para 20-4). As air traffic conditions change, the controller revises the expected approach clearance time and advises the aviator accordingly. When the aviator is cleared for the approach, he may immediately begin the descent from the 3,000-foot holding altitude to the 1,700-foot procedure turn altitude, regardless of his position in the holding pattern. The final turn inbound from the holding pattern serves as the procedure turn, so the aviator could extend the outbound leg to lose altitude if necessary, provided he does not exceed the 10 nautical miles (fig 20-1) prior to turning inbound. Since this approach is an ON airport VOR approach, the final segment on the approach begins with completion of the procedure turn.

b. Descent from the procedure turn altitude may be initiated when the aircraft has intercepted the final approach course inbound. So that visual reference with the runway environment can be established as early as possible before reaching the missed approach point (MAP), the descent to the MDA should be made without delay. An effort should be made to arrive at the MDA with enough time/distance remaining to identify the runway environment and descend from the MDA to touch down at or near the normal approach angle and descent rate for the aircraft. If the approach clearance did not state that circling to another runway would be required, the aviator will use the MDA for a straight-in approach to runway 6 (S-6) according to the category of his aircraft. If circling to another runway is required, the aviator will use the MDA for circling according to the category of his aircraft.

c. Descent below the MDA is not authorized until the pilot establishes visual contact with the runway environment and can reasonably expect to maintain visual contact throughout the landing. In making an ON airport VOR approach, the VOR is the missed approach point. Should the aviator not make visual contact by the time he reaches the VOR, he would execute a missed approach (para 20-9).

Note. **Where the VOR station is located away from the airport, descent is restricted to minimum altitude prior to reaching the final approach fix. After passing the final approach fix inbound, descent to minimum descent altitude is authorized. The missed approach point is determined by computing the flight time from the final approach fix to the landing runway. The missed approach must be executed at the expiration of this time even if the aircraft has not reached the appropriate MDA.**

20-8. LANDING

Landing clearance will be issued by ATC during the approach. If visual reference is lost while circling to land from an instrument approach, the missed approach procedure will be executed. To become established on the prescribed missed approach course, the aviator should make an initial climbing turn toward the landing runway and continue the turn until he is established on the missed approach course.

20-9. MISSED APPROACH

If for any reason the landing is not accomplished, the aviator executes the missed approach procedure. To accomplish the procedure as specified in figure 20-1, the aviator—

a. Adjusts power and attitude, as necessary, to begin an immediate climb.

b. Turns right to intercept the 180-degree radial of Cairns VOR.

c. Sets the course selector to 180°. (This results in a FROM indication and a right needle deflection on the course indicator.)

d. Reports a missed approach and includes the reason (unless initiated by ATC) to the controller and requests further clearance, either for another approach or to his alternate airport, as appropriate. (If he requests clearance to the alternate, flight plan data must be given to the controller.)

e. Checks for centered needle at the 180-degree radial.

f. Continues climb to missed approach altitude (2,000 feet).

g. Complies with subsequent ATC instructions.

Section III. TYPICAL NDB APPROACH USING AUTOMATIC DIRECTION FINDER (ADF) PROCEDURES

20-10. GENERAL

NDB approach charts (fig 20-5) are similar in appearance and format to VOR approach charts discussed in the previous section. The approach procedures are essentially the same as those for VOR. In the event of an RMI malfunction, fixed card ADF procedures must be used.

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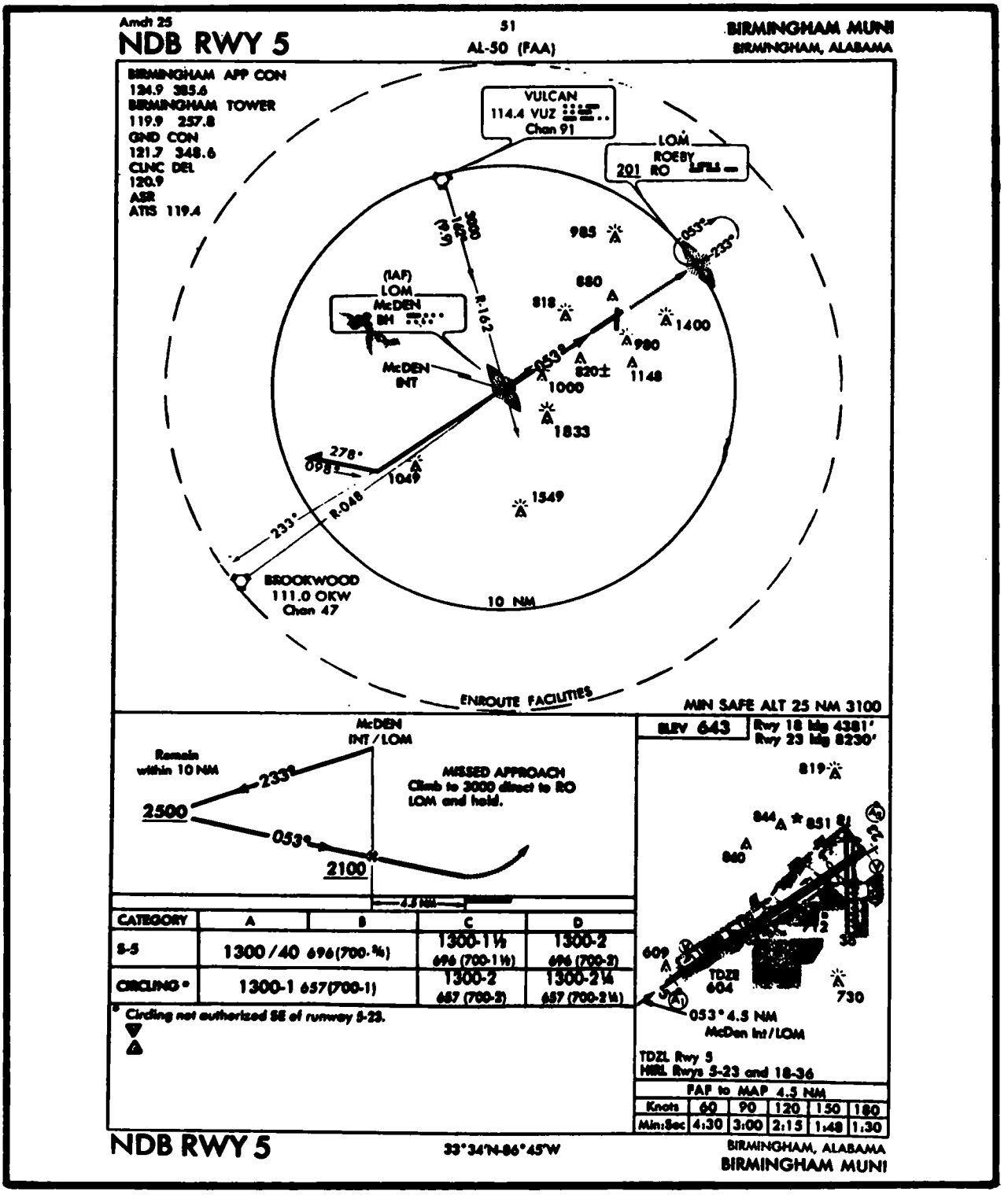


Figure 20-5. NDB approach chart.

20-11. [illegible]

Figure 20-6 shows an aircraft (and the associated instrument indications) as it approaches the McDen NDB on an inbound course of 304° at 5,000 feet. The pilot will execute an NDB approach to runway 5 at Birmingham Municipal Airport (fig 20-5). The aviator has been cleared to hold southwest of the McDen outer marker (OM) on a 053° course to the outer marker, left turns. He is cleared to descend and maintain 4,000 feet and given an expected approach clearance time of 1730. Upon arrival at McDen outer locator at 4,000 feet, the aviator—

a. Notes the time.

b. Begins his turn outbound.

c. Reduces airspeed to the prescribed holding speed if not done previously.

Note. **Airspeed reduction is initiated when 3 minutes or less from the holding fix. However, cross the holding fix initially at or below maximum holding airspeed.**

d. Reports to ATC if required.

Note. **Actions "a" through "c" are performed almost simultaneously. The report is not made until after station passage.**

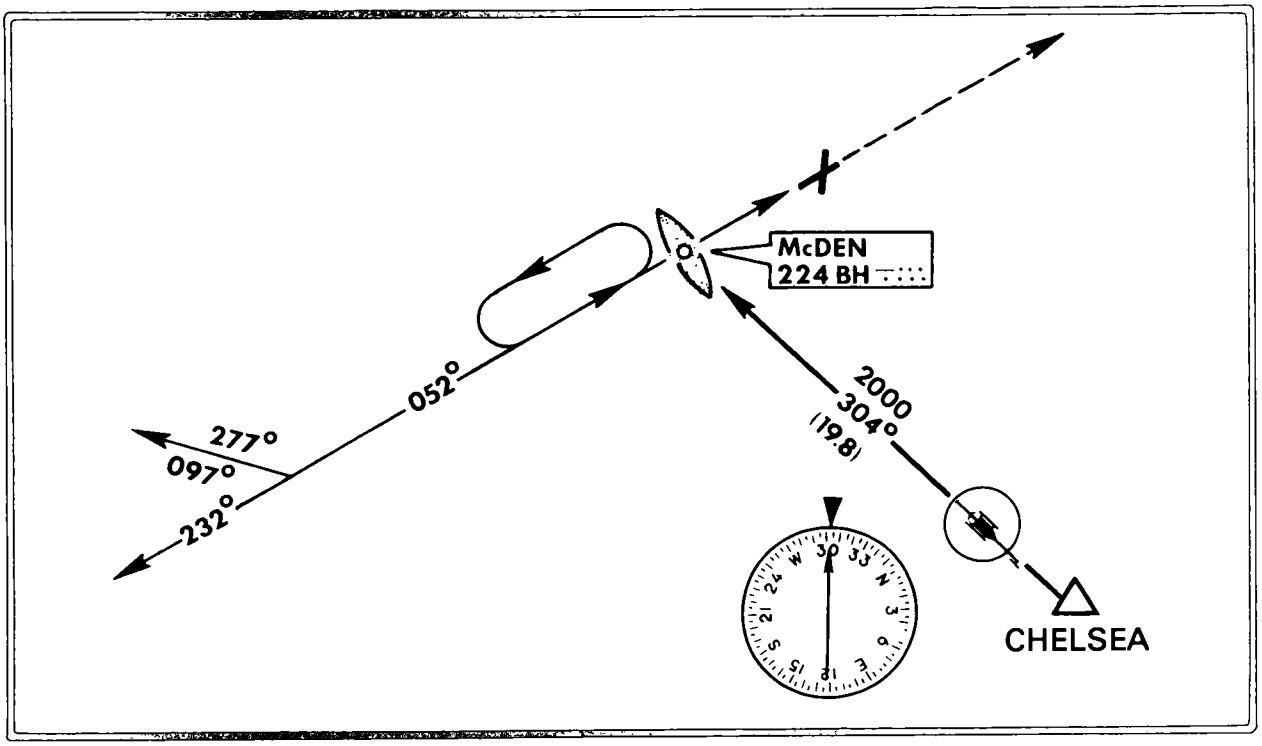


Figure 20-6. NDB arrival.

Figure 20-7 shows the NDB holding pattern entry procedure and instrument readings during entry to the pattern. The aviator arrives at BH and accomplishes the normal entry into the left-hand holding pattern by turning parallel to the outbound heading on the holding side.

a. *Point A.* After passing BH inbound, the aviator observes station passage (the No. 1 needle—the bearing pointer—will begin to oscillate and then deflect into the lower half of the RMI compass card). The aviator will then begin his standard rate turn to the left. At point A, the aircraft is on a heading of 233°. The bearing pointer indicates that the station is to the left rear of the aircraft. The tail of the bearing pointer indicates the bearing from the station on which the aircraft is located (300°) and the head of the bearing pointer indicates the magnetic direction to the station (120°).

b. *Point B.* The aircraft has flown outbound for approximately 1 minute and has begun a turn to intercept the inbound course of 053°. During the turn, the aviator should monitor the heading indicator and movement of the bearing pointer and should adjust the rate of turn in order to roll out on the 053° course to the beacon.

c. *Point C.* The aircraft is inbound to the station on a heading of 053° as shown. The bearing pointer indicates that the magnetic direction to the station is also 053°. Therefore, the aircraft is tracking "on-course" to the station. Throughout the inbound leg, the aviator should determine the drift correction (if any) to maintain his desired track and the flight time from rollout to station passage in order to adjust subsequent legs.

Figure 20-8 shows the holding pattern with aircraft locations shown at various points in the pattern.

a. *Point A.* After passing the beacon inbound, the aviator begins the left turn to the outbound heading.

b. *Point B.* As the aviator completes the turn to the outbound heading, adjusting for drift correction, he monitors the ADF indicator to determine when he is abeam the station. When the indicator reaches the 90-degree position (143° in this case), the aircraft is abeam the station and the timing for the outbound leg begins.

c. *Point C.* Having flown the required outbound time (based on the desired inbound time of 1 minute), the aviator begins a left turn to reintercept the 053° inbound course.

d. *Point D.* The aviator again establishes the aircraft on the inbound course of 053° and rechecks his timing and drift correction for further refinements.

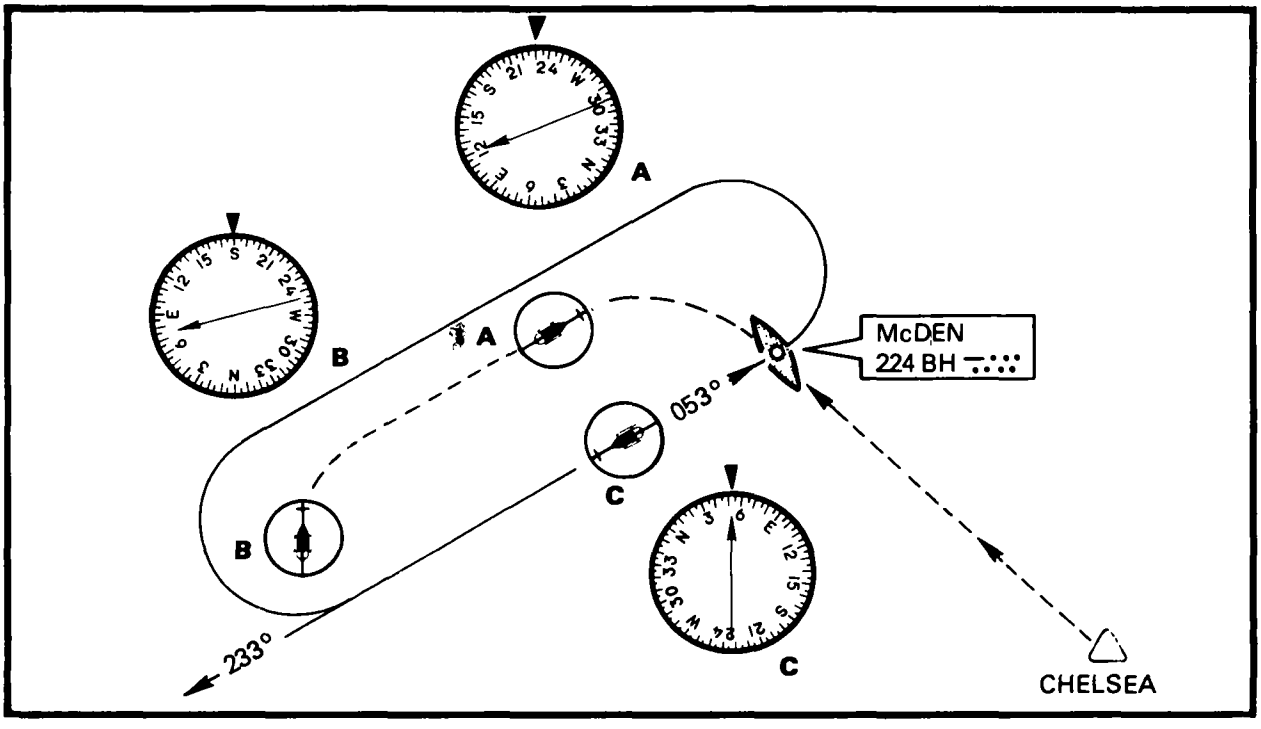


Figure 20-7. NDB holding pattern entry.

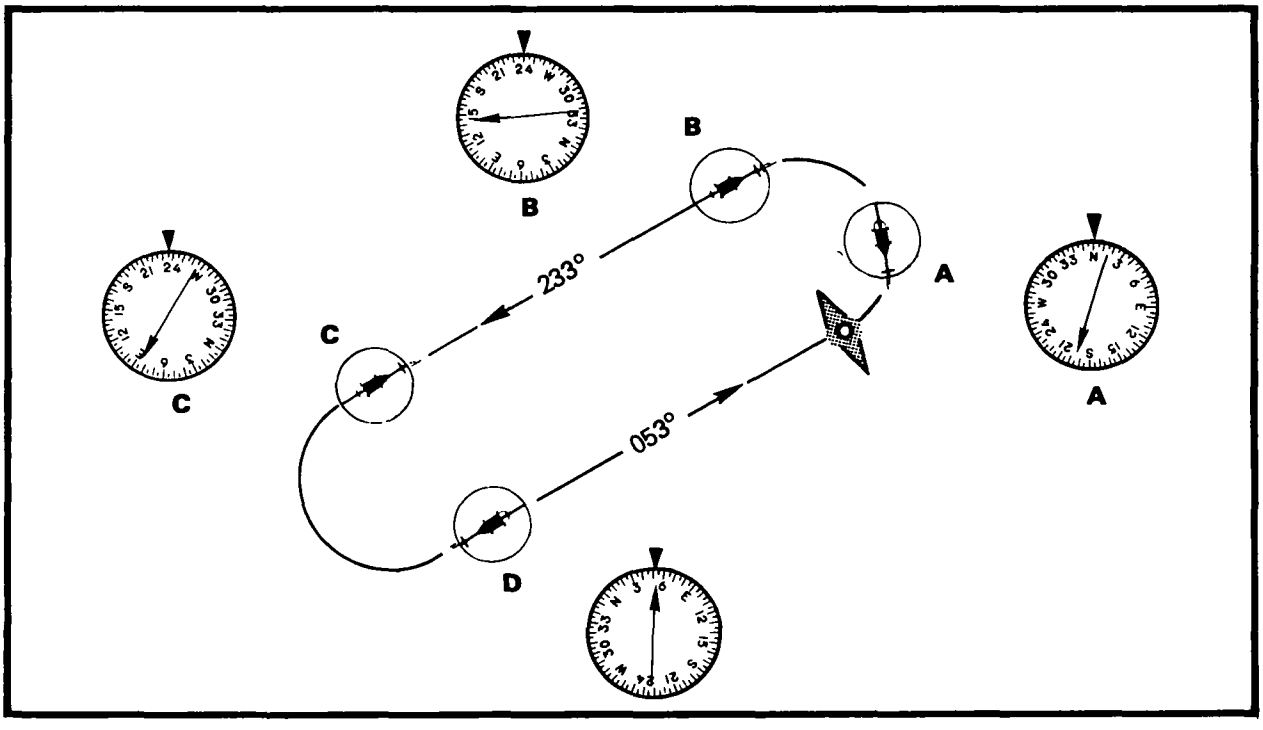


Figure 20-8. NDB holding pattern procedure.

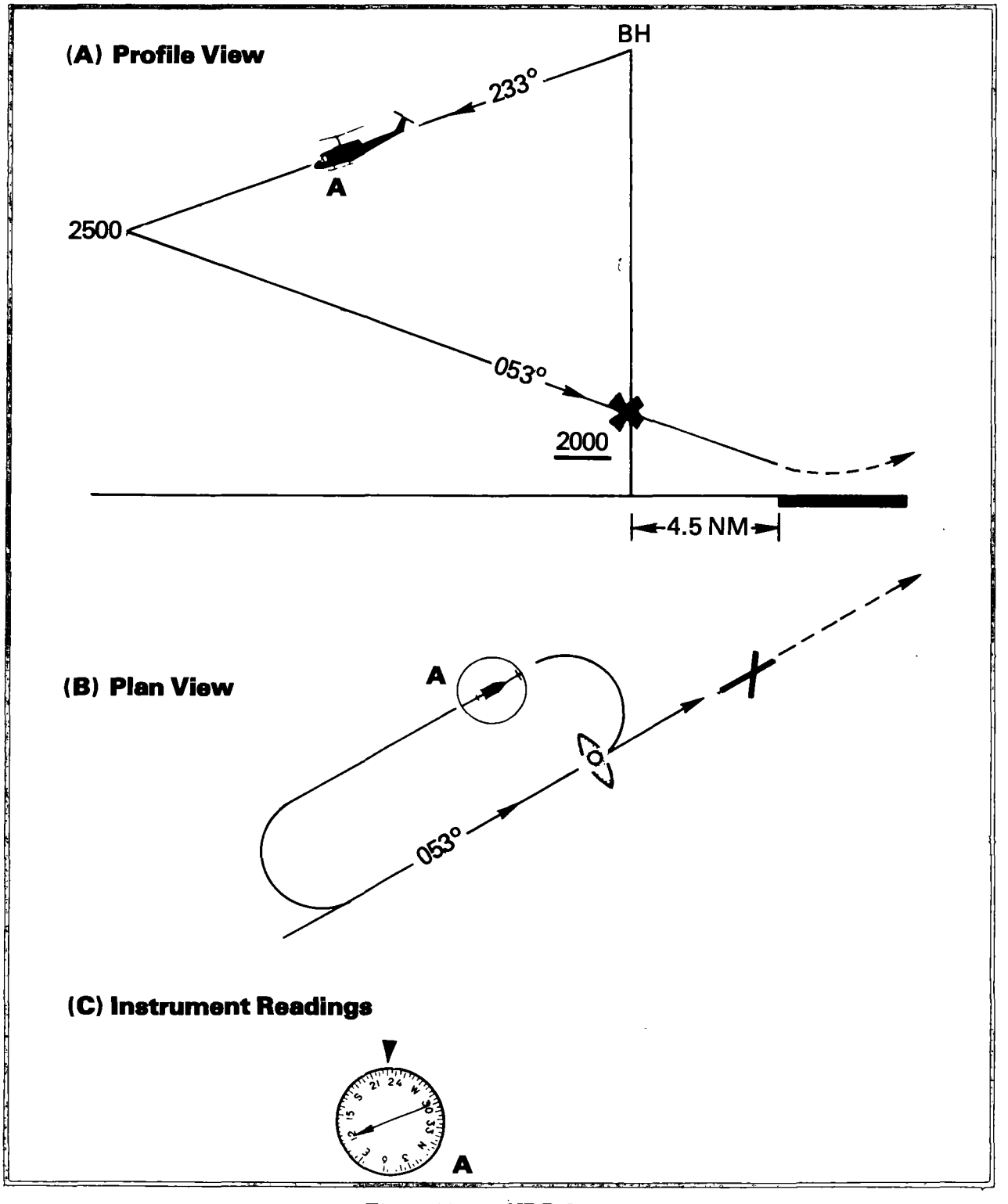


Figure 20-9. NDB descent.

20-14. DESCENT

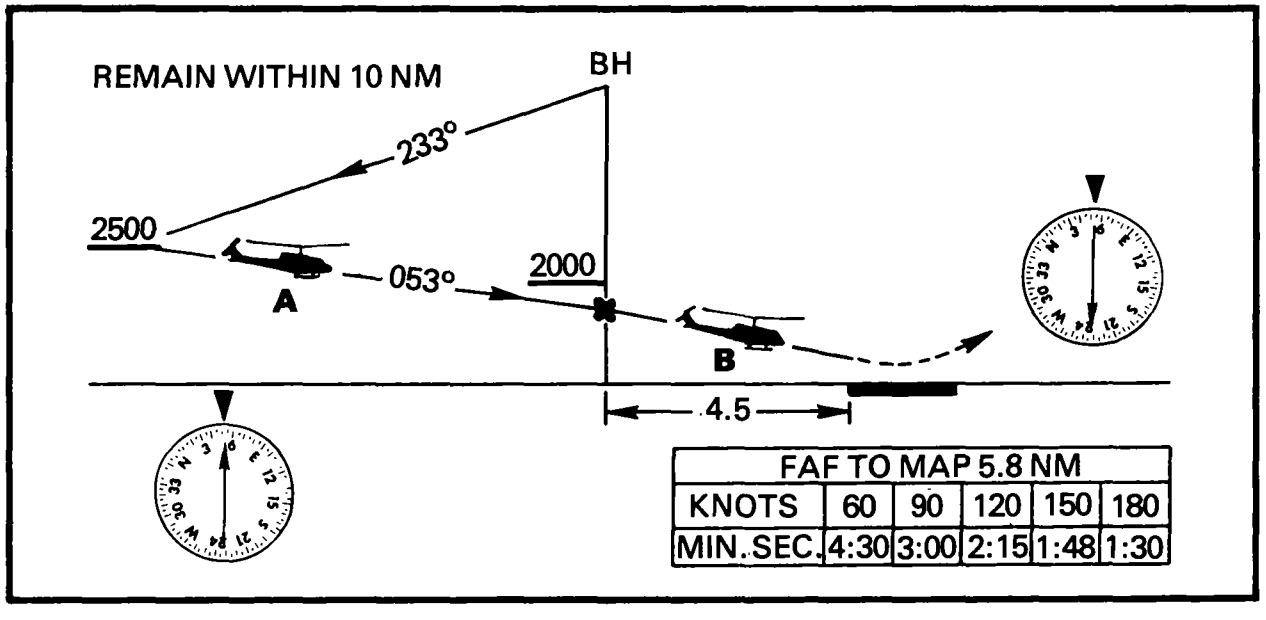
Figure 20-9 shows the NDB descent procedure from the holding pattern and should be used in conjunction with figure 20-5. At point A, the aviator has received approach clearance and has begun his descent to procedure turn altitude (2,500 feet) while in the holding pattern. Because he is established in the holding pattern, the published procedure turn is not required as the turn inbound serves as the procedure turn..

Note. After receiving approach clearance, the aviator may disregard the time restrictions for the outbound and inbound legs. However, he must remain within his airspace limitations as depicted on the approach chart (in this case, 10 NM). No extension would be allowed for those procedures using a holding pattern in lieu of procedure turn.

In the event the aviator has been issued approach clearance while inbound to McDen (locator outer marker (LOM)), he would have turned and intercepted the outbound course (233°) after arrival at McDen and executed the procedure turn. (See chapter 19 for a discussion of procedure turns.)

20-15. NDB [illegible] APPROACH

a. Figure 20-10 shows the procedure and instrument readings during the intermediate and final segment of the approach. After completing the turn inbound, the aviator intercepts the 053° inbound course and descends to 2,100 feet (the minimum authorized altitude prior to reaching the final approach fix (FAF) (BH)).



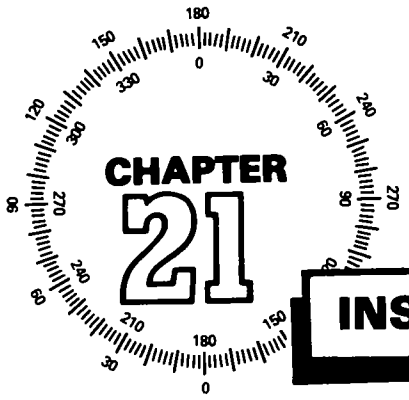
FAF TO MAP 5.8 NM					
KNOTS	60	90	120	150	180
MIN.SEC.	4:30	3:00	2:15	1:48	1:30

Figure 20-10. NDB intermediate and final approach.

b. When the aviator observes station passage, he notes the time, begins his descent to the minimum descent altitude, and reports the beacon inbound. The descent to the MDA (1,300 feet for a straight-in approach or a circling approach) to another runway (fig 20-5) should be made without delay, using a rate of descent not to exceed 500 fpm, so that visual reference with the runway environment can be established as early as possible before reaching the missed approach point. However, descent below the appropriate MDA is not authorized until the aviator establishes visual contact with the runway environment and can reasonably expect to maintain visual contact throughout the landing.

c. In this approach, the facility (BH) is located OFF airport (para 20-3) and the aviator will continue to fly toward the airfield at the MDA for the time computed, based on the distance to the missed approach point and the estimated groundspeed (fig 20-10). For this approach, the distance from the final approach fix (BH) to the missed approach point is 4.5 NM. If the aviator has computed his groundspeed to be 90 knots, the flight time for this segment of the approach is 3 minutes. If the MDA is reached prior to the expiration of the 3-minute time period, the aviator will maintain this altitude and continue on course. A missed approach will be executed 3 minutes after leaving the final approach if visual contact with the runway environment has not been established.

Note. For NDB approaches, the MAP is determined by computing the flight time from the FAF and must be executed at the expiration of this time even if the aircraft has not reached the appropriate MDA.



CHAPTER 21

INSTRUMENT LANDING SYSTEM (ILS)

Section I. GENERAL

21-1. INTRODUCTION

The instrument landing system is a complex array of radio and visual navigational aids (NAVAID). It is the most efficient system in widespread use for safe landing under the lowest ceiling and visibility conditions permitted by obstruction clearance criteria. Its effectiveness as an approach aid is matched by radar (chap 22), but the preferred system at most major air terminals is the ILS supplemented by radar. More advanced systems have been undergoing tests for several years, but several factors have prevented placing these systems in an operational status.

21-2. GROUND COMPONENTS

a. *Basic Components.* The basic ground components of an ILS are the localizer (LOC), glide slope (GS), outer marker (OM), and middle marker (MM). The approach lights are visual aids normally associated with the ILS. Compass locator or precision radar may be substituted for the OM or MM. Surveillance radar may be substituted for the outer marker.

b. *Supplementary Components.* The ILS is frequently supplemented by installing one or more of the following approach aids:

(1) *Compass locators* (para 21-5f).

(2) *Transmissometers.* This device "looks" instrumentally down the instrument runway in the landing direction and either determines the runway visibility by reference to ordinary runway lights or computes the runway visual range (RVR) (para 21-10) by reference to high intensity runway lights.

(3) *Surveillance and precision radar systems* (chap 22).

(4) *Distance measuring equipment (DME).* This aid, although normally installed at VHF omnidirectional range (VOR), tactical air navigation (TACAN), and VOR and TACAN navigational facilities—collocated (VORTAC) sites, is occasionally collocated with the instrument landing system. With proper airborne receiving equipment, the aviator can read the distance to or from the transmitter at all times.

(5) *Visual approach slope indicator (VASI).* The VASI gives visual descent guidance information during the approach to a runway. The standard VASI consists of downwind and upwind light bars that provide a visual glidepath which provides safe clearance of obstructions within the approach zone. Lateral course guidance is provided by the runway or runway lights. Descent, using the VASI, should not be initiated until the aircraft is visually alined with the runway. Refer to the Federal Aviation Administration (FAA) *Airman's Information Manual* basic, flight, and air traffic control (ATC) procedures for an up-to-date discussion of the VASI systems and their use.

(6) *Instrument approach lighting systems.* Instrument approach lighting systems provide the basic means for transition from instrument flight using electronic approach aids to visual flight and landing. Operational requirements dictate the sophistication and configuration of the approach light system for a particular airport. Refer to the legend of any volume of flight information publication (FLIP) instrument approach procedures for a display of various approach lighting systems.

(7) *Runway marking.* For a discussion of instrument runway marking, see paragraph 60 of the *Airman's Information Manual.*

(a) *Condenser-discharge sequenced flashing light system.* This instrument approach lighting system is installed, in conjunction with the instrument approach light system, at some airports which have US Standard "A" approach lights as a further aid to pilots making instrument approaches. The system consists of a series of brilliant blue-white bursts of light flashing in sequence along the approach lights. It gives the effect of a ball of light traveling toward the runway.

(b) *Runway edge lights.* These lights are used to outline the edge of the runway during periods of darkness and restricted visibility conditions. They are classified according to the intensity or brightness they are capable of producing. This light system consists of the high

intensity runway lights (HIRL), medium intensity runway lights (MIRL), and the low intensity runway lights (LIRL). The HIRL and MIRL systems have variable intensity controls, whereas the LIRL system normally has one intensity setting.

(c) *In-runway lighting aids.* Touchdown zone lighting and runway centerline lighting are installed on some precision approach runways to facilitate landing under adverse visibility conditions. Taxiways turnoff lights may be added to expedite movement of aircraft from the runway.

(*1*) *Touchdown zone lighting*—two rows of transverse light bars disposed symmetrically about the runway centerline in the runway touchdown zone. The system generally extends from 75 feet to 125 feet of the landing threshold to 3,000 feet down the runway.

(*2*) *Runway centerline lighting*—flush centerline lights spaced at 50-foot intervals beginning 75 feet from the landing threshold and extending to within 75 feet of the opposite end of the runway.

(*3*) *Runway remaining lights*—applied to centerline lighting systems in the final 3,000 feet as viewed from the takeoff or approach position. Alternate red and white lights are seen from the 3,000-foot points to the 1,000-foot points, and all red lights are seen for the last 1,000 feet of the runway. From the opposite direction, these lights are seen as white lights.

(*4*) *Taxiway turnoff lights*—flush lights spaced at 50-foot intervals, defining the curved path of aircraft travel from the runway centerline to a point on the taxiway.

(d) *Runway end identifier lights (REIL).* These lights are installed at many airfields to provide rapid and positive identification of the approach end of a particular runway. The system consists of a pair of synchronized flashing lights, one of which is located laterally on each side of the runway threshold facing the approach area.

Note. **Consult FLIP *IFR Supplement* to determine the exact supplementary components of the ILS that are available for a specific airport.**

Section II. OPERATION AND FLIGHT USE

21-3. LOCALIZER

a. *Location and Signal Pattern (fig 21-1).* The localizer transmitter is located beyond and near the end of the primary instrument runway opposite the approach end. It produces two signal patterns which overlap along the runway centerline and extend in both directions from the transmitter. One side of the signal pattern is

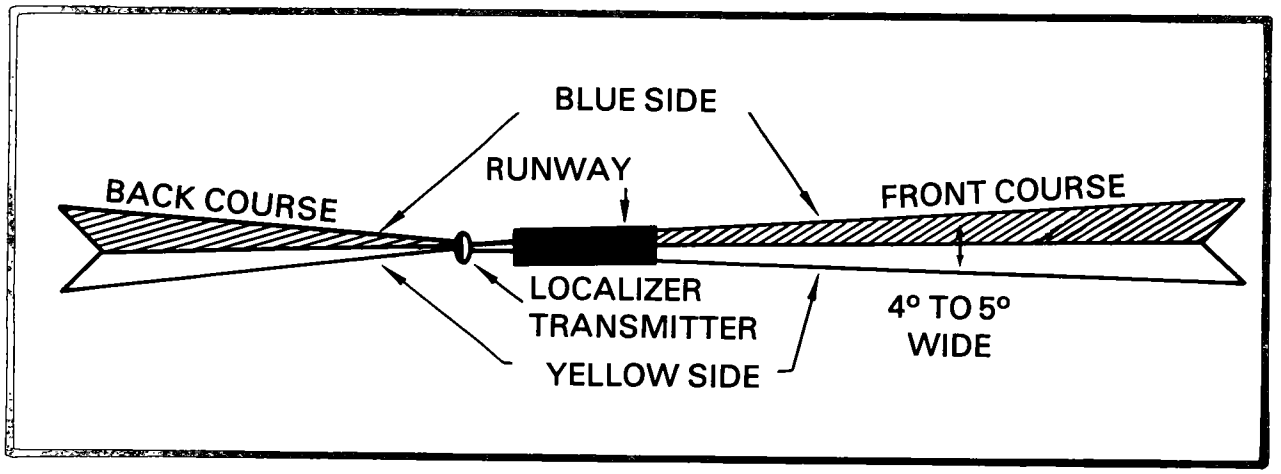


Figure 21-1. Sample ILS localizer location and signal pattern.

referred to as the *blue* sector, the other as the *yellow* sector. The "beam" produced by the overlap of the sectors is usually from 4° to 5° wide. The portion of the beam extending from the transmitter toward the outer marker (fig 21-1) is called the *front course.* The sectors are arranged so that, when flying inbound toward the runway on the front course, the blue sector is to the right of the aircraft and the yellow sector to the left. While flying inbound on the *back course* (extending from the transmitter to the left (fig 21-1)), the blue sector is to the left of the aircraft and the yellow sector is to the right. Both the front course and the back course may be approved for instrument approaches; however, only the front course will be equipped with associated compass locators and lighting aids. (Some major airports are equipped with more than one complete ILS system, thus providing a front course for each end of a selected runway. Normally, only one ILS will be operated at a time.) The localizer provides course guidance throughout the descent path to the runway threshold from a distance of 18 NM from the antenna. Proper off-course indications are provided throughout the following angular areas of the operational service volume: (1) to 10° either side of the course along a radius of 18 NM from the antenna, and (2) from 10° to 35° either side of the course along a radius of 10 NM. Generally, proper off-course indications are provided to 90° either side of the localizer course; however, some facilities cannot provide angular coverage to that extent because of siting characteristics or antenna configurations or both. Therefore, instrument indications of possible courses in the area from 35° to 90° should be disregarded.

b. *Receiver Operation.* Army very high frequency (VHF) navigation receivers will receive the localizer signal in the frequency range of 108.1 megahertz (MHz) to 111.95 MHz. Tuning of the localizer frequency into the receiver will activate the course deviation indicator of the course indicator instrument. The localizer signal received will identify the station by the three-letter identification of the station preceded by the letter "I"; e.g., I OZR which identifies the Cairns Army airfield (AAF) localizer as printed in the instrument approach chart. The localizer is usually capable of transmitting voice. Reliable reception of the localizer signal will be indicated by activation of the course deviation indicator,

disappearance of the "OFF" flag associated with the course deviation indicator, and reception of the coded identifier. No "TO-FROM" indication will be displayed. When a localizer frequency is tuned, the course selector setting has no effect on the course deviation indicator as it does when a VOR frequency is tuned. However, if the course indicator has a heading pointer, the inbound heading of the ILS course should be set on the course indicator so that the heading pointer will be directional in its operation. Turning on and operation of the localizer receiver will be described in the operator's manual for the aircraft.

c. *Localizer Tracking (fig 21-2).* When the aircraft is proceeding inbound on the front course or outbound on the back course, the indications of the course deviation indicator are directional; that is, if the deviation needle is deflected to the right of center, the localizer is to the right of the aircraft and a turn to the right will be required to return to course and center the needle. However, if the aircraft is flying inbound on the back course or outbound on the front course, the deviation indicator is no longer directional; that is, if the deviation needle is deflected to the left, the localizer course is to the right and a turn to

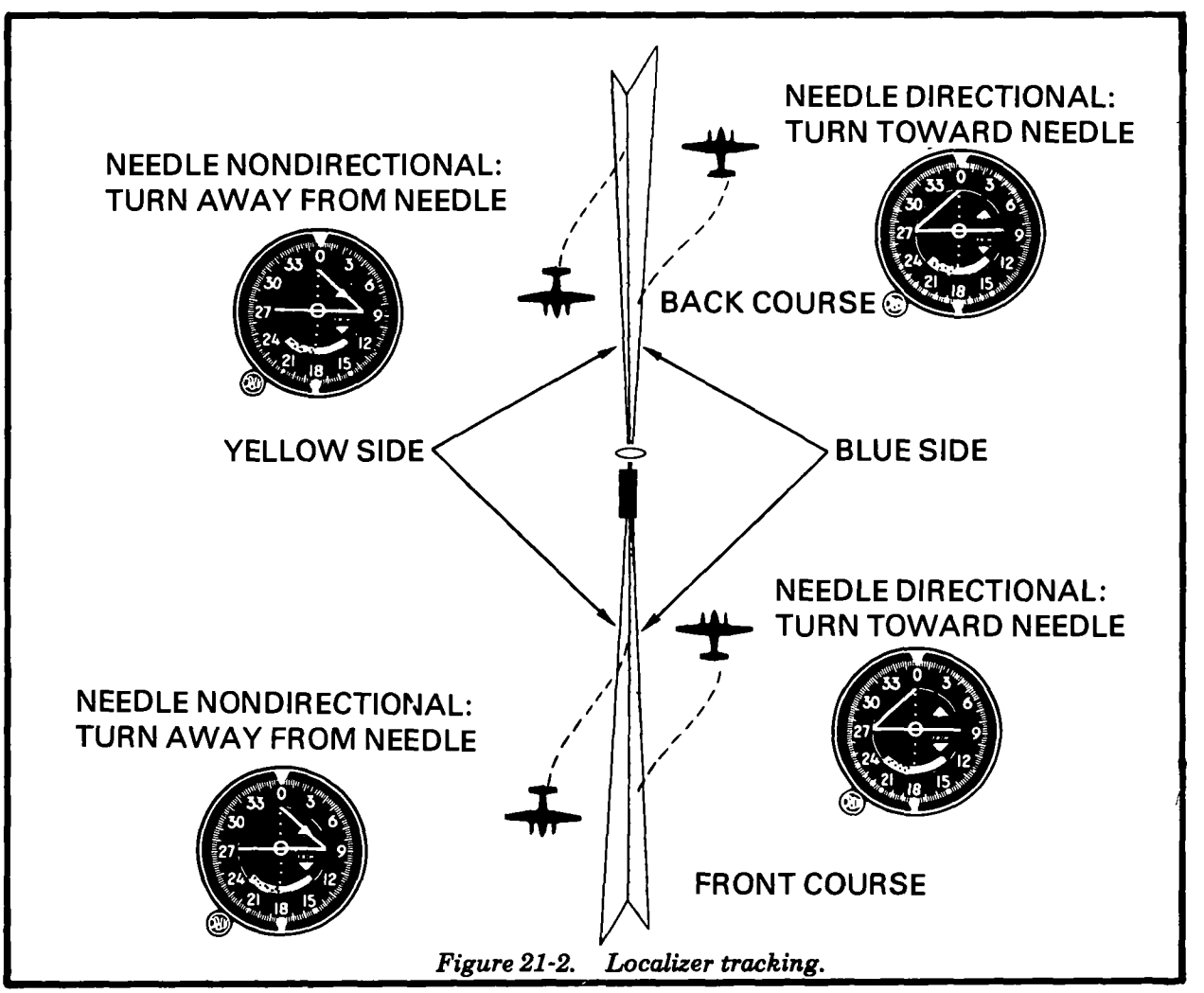


Figure 21-2. Localizer tracking.

the right will be required to return to course and center the needle.

Note. Some aircraft ILS equipment has a reverse sensing capability and the deviation needle is always directional.

Some course indicators have the sector colors (blue, yellow) printed on the face just below the course deviation indicator. The deviation needle is always deflected into the colored area corresponding to the color indicated on the ILS approach chart. This aids the aviator in determining the position of the aircraft in relation to the localizer course and the direction of the correction to be applied. The amount of correction to return to the localizer course will depend on the distance between the aircraft and the transmitter and on the direction and velocity of the wind. Also, the aviator must remember that the needle sensitivity when tuned to ILS is different from that of the VOR. Whereas, the needle sensitivity on VOR is a total of 20° (10° either side of the center point), the needle sensitivity is a total of 4° to 5° on the localizer (approximately 2½° either side of the center point). The amount of correction to the localizer course should begin with 5° and be narrowed down to 2° as the transmitter is approached and the signal pattern narrows. These recommended corrections may be modified as necessary until the wind correction is determined.

a. *Transmitter Location.* The glide slope transmitter radiates its signals primarily outward along the localizer front course in the direction of the outer marker (fig 21-3). There are numerous false glide slope signals which are radiated simultaneously with the desired signal. Glide slope indications must be ignored unless the aircraft is at or near the appropriate approach procedure altitude, within the limits of the localizer course, and the approach procedure is specifically named on the approach "ILS." However, there are some runways at which an additional glide slope transmitter is installed to radiate signals primarily directed outbound on the localizer back course. On runways so equipped, the two glide slopes cannot be operated simultaneously. Glide slope transmitters are located from 400 to 600 feet to one side of the runway centerline on the approach end.

b. *Receiver Operation.* Glide slope frequencies are paired with localizer frequencies in predesignated combinations. Receivers will automatically tune the paired glide slope frequency whenever the localizer frequency is tuned. Reliable reception of the glide slope will be indicated by the activation of the glide slope indicator and the disappearance of the "OFF" flag located on the face of the course indicator near the glide slope indicator.

c. *Glide Slope Indicator.* The indications of the needle are always directional; i.e., if the aircraft is below the glide slope

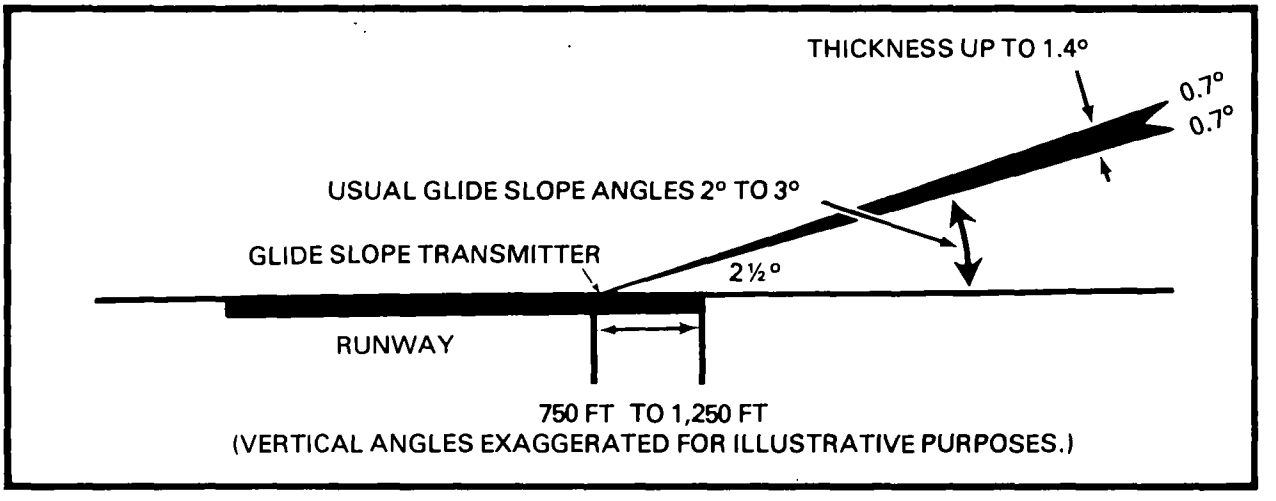


Figure 21-3. Typical glide slope transmitter installation.

(A, fig 21-4), the needle will be deflected upward from the centered position. The aviator must make a pitch attitude/power adjustment to maintain the airspeed within acceptable limits and to decrease the rate of descent or level off temporarily in order to reintercept the glide slope. If the aircraft is above the glide slope (B, fig 21-4), the pitch attitude/power must be adjusted to maintain the airspeed within acceptable limits and to increase the rate of descent in order to reintercept the glide slope. The aviator should be aware of the obstruction clearance criteria for the final segment of precision approaches so that the need for remaining on course and on or above the glide slope is apparent. Even after visual contact has been established with the approach lights or runway, it is recommended that the glide slope be followed

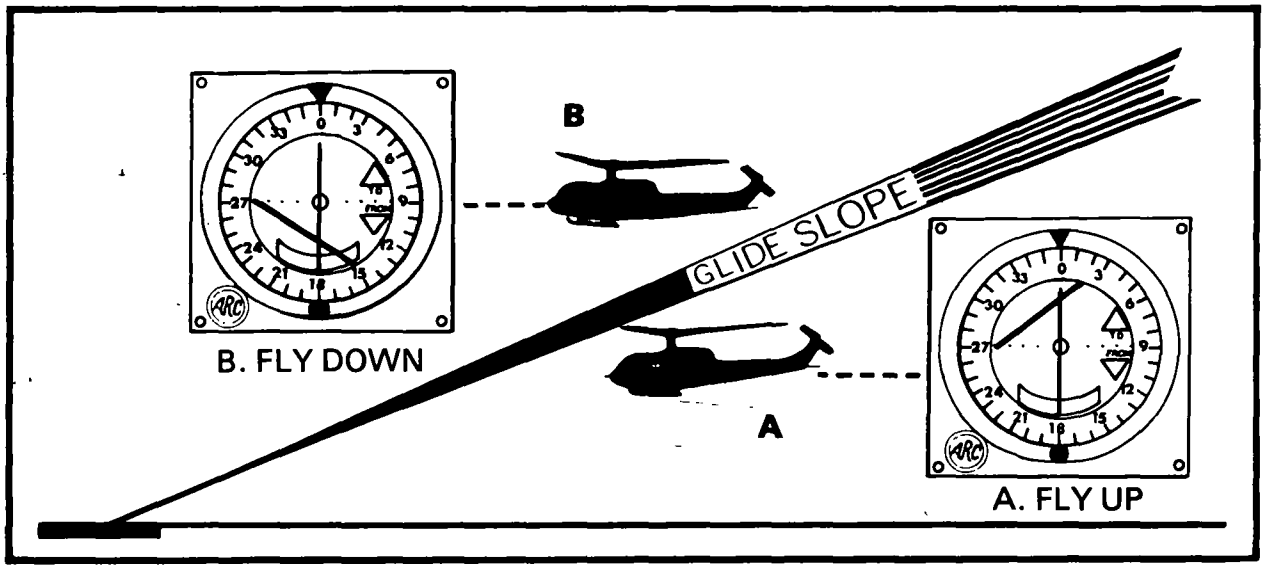


Figure 21-4. Directional aspect of glide slope indicator.

until the aircraft is definitely past the field boundary or is approaching the runway overrun. This will aid in preventing a landing short of the runway. Also, if stratus or fog is momentarily flown through, the aviator may have the illusion that the pitch attitude of the aircraft has moved upward. If the glide slope is still being flown, the aviator can tell at a quick glance that his pitch attitude is normal and has not changed. This will prevent him from making a pitch adjustment downward and cause the aircraft to contact the ground short of the runway at a high rate of descent.

21-5. MA[illegible]

a. *Marker Beacons.* A marker beacon is a radio facility capable of transmitting a signal in a vertical direction only. Its signal is received only while flying over the facility (fig 21-5) within the signal radiation pattern. The primary purpose of the marker beacon is to provide the aviator with a definite radio position fix. The horizontal cross section of the vertical radiation pattern of a marker beacon used with ILS is the elliptical pattern. It is quite narrow so that an aircraft will pass through the pattern rapidly, thereby insuring the accuracy of the fix. Since all marker beacons transmit on a frequency of 75 MHz, the receiver is preset to a 75-megahertz frequency to receive signals from any beacon. The marker beacon signal is modulated with a coded (or continuous) audio frequency for identification purposes. The marker beacon receiver is arranged so that the signal can be either heard in the headset or seen as a marker beacon light on the aircraft's instrument panel, or both.

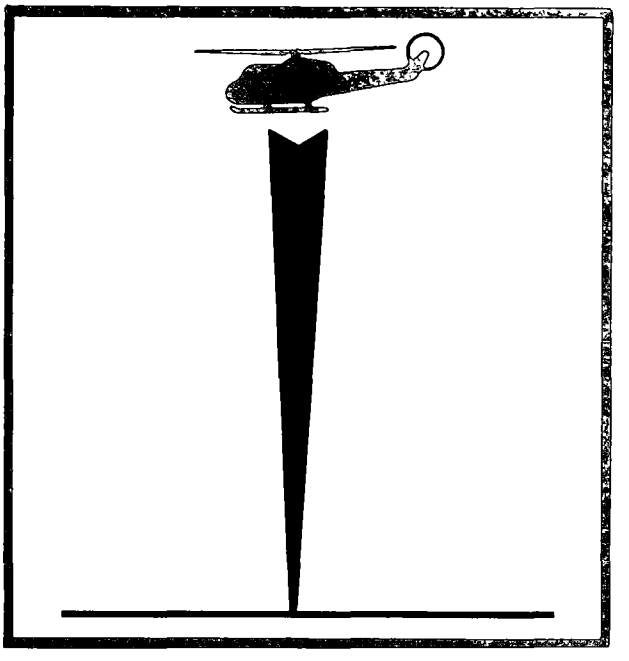


Figure 21-5. Marker beacon signal pattern (vertical cross section).

b. *Outer Marker.* The outer marker normally indicates a position at which an aircraft at the appropriate altitude on the localizer course will intercept the ILS glidepath (fig 21-6). The OM is identified with continuous dashes at the rate of two dashes per second.

c. *Middle Marker.* The middle marker indicates a position at which an aircraft is approximately 3,500 feet from the landing threshold (fig 21-6). This will also be the position at which an aircraft on the glide slope will be at an altitude of approximately 200 feet above the elevation of the touchdown zone. The MM is identified with alternate dots and dashes keyed at the rate of 95 dot/dash combinations per minute.

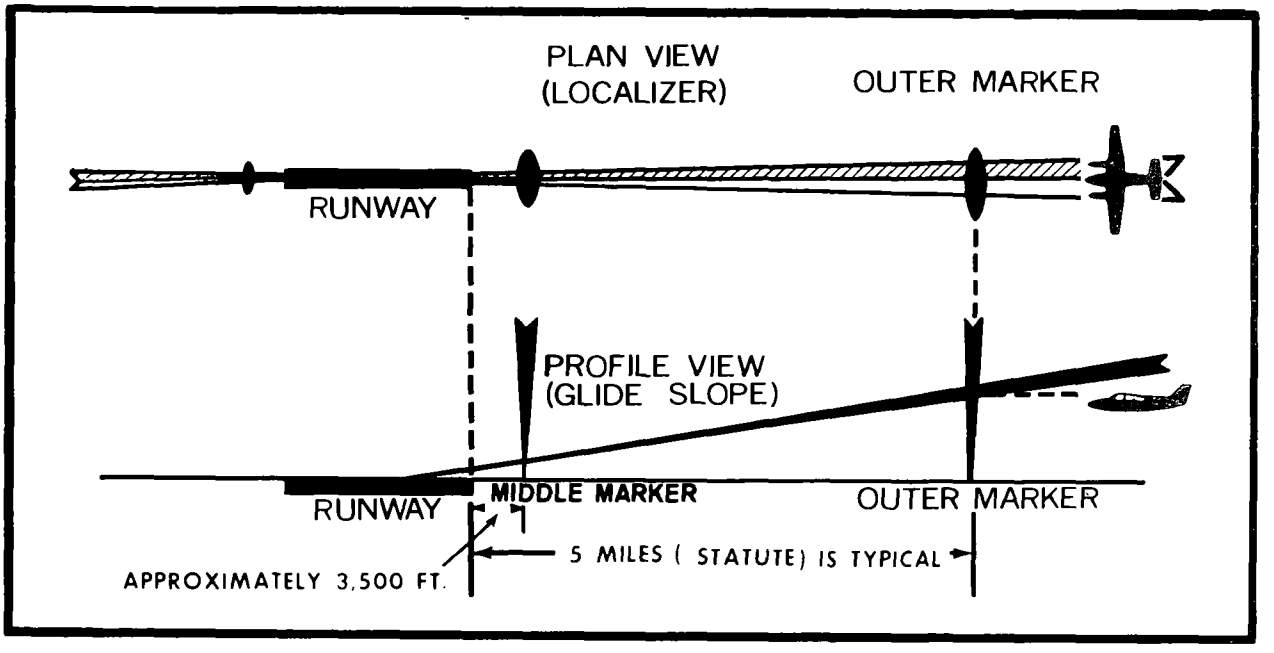


Figure 21-6. Outer and middle marker locations and signal pattern.

d. *Inner Marker (IM).* The inner marker, where installed, will indicate a point at which an aircraft is at a designated decision height (DH) on the glidepath between the middle marker and the landing threshold. This is for category II ILS approaches. The IM is identified with continuous dots keyed at the rate of six dots per second.

e. *Back Course Marker.* A back course marker, where installed, normally indicates the ILS back course final approach fix (FAF) where approach descent is started. The back course marker is identified with two dots at a rate of 72 to 95 two-dot combinations per minute.

f. *Compass Locators.* Compass locator transmitters (fig 21-7) are often situated at the outer marker site and occasionally found at a middle marker site. They have a power of less than 25 watts, a range of at least 15 miles, and operate between 200 and 415 kHz. At some locations, higher powered radio beacons, up to 400 watts, are used as outer marker compass locators. These generally carry transcribed weather broadcast information. Compass locators transmit two-letter identification groups. The locator outer marker (LOM) transmits the first two letters of the localizer identification group, and the locator middle marker (LMM) transmits the last two letters of the localizer identification group.

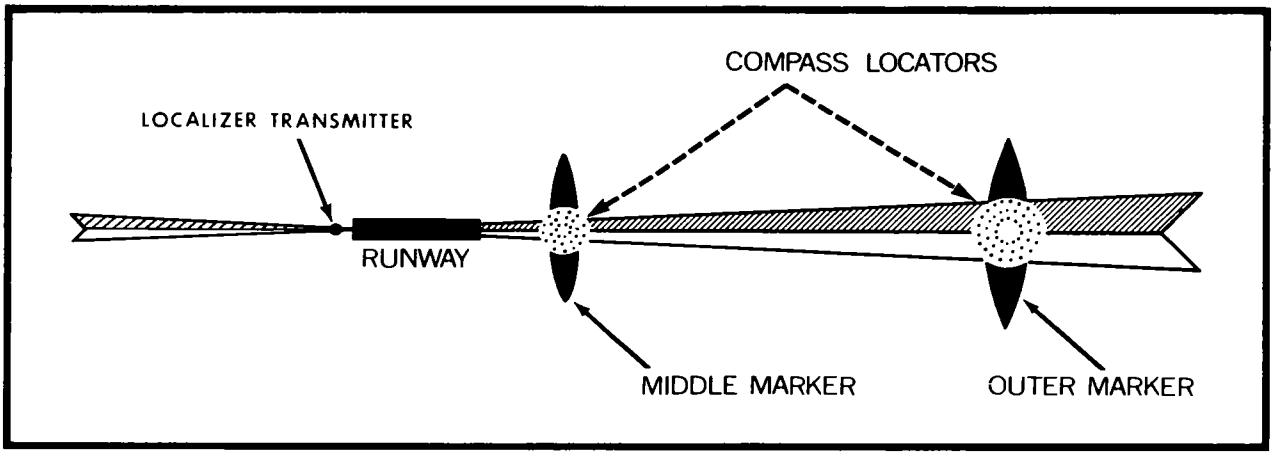


Figure 21-7. Compass locator positions.

21-6. AREA OF SURFACE

Figure 21-8 shows the Cairns AAF instrument landing system and surrounding airways and related facilities. Figure 21-9 shows the ILS runway 6 approach chart for Cairns AAF. Unless being radar vectored to the ILS final approach course (chap 22), aircraft inbound to an airport for an ILS approach will usually be cleared via a feeder route from a fix on their route of flight to the locator outer marker to join the

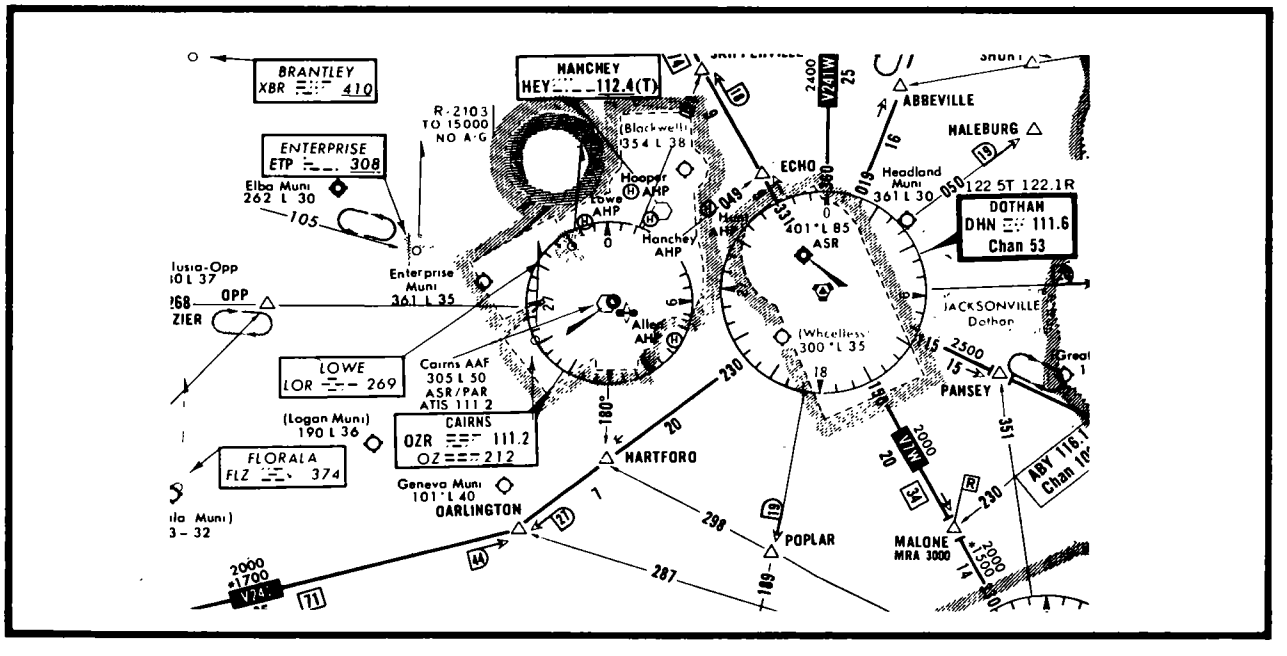


Figure 21-8. Area chart representation.

localizer course. Figure 21-9 shows several feeder routes to the Cairns LOM. These routes are indicated by an arrow to the LOM and contain information concerning the course from the enroute fix to the LOM, distance, and minimum altitude. If ATC clears the aircraft for the ILS approach prior to reaching the LOM, the aircraft may descend to the minimum altitude for the feeder route if the aviator so desires. If holding instructions are received, the aircraft will maintain the altitude assigned by air traffic control (ATC). Prior to reaching the enroute fix and starting the feeder route, the aviator should tune the automatic direction finder (ADF) receiver

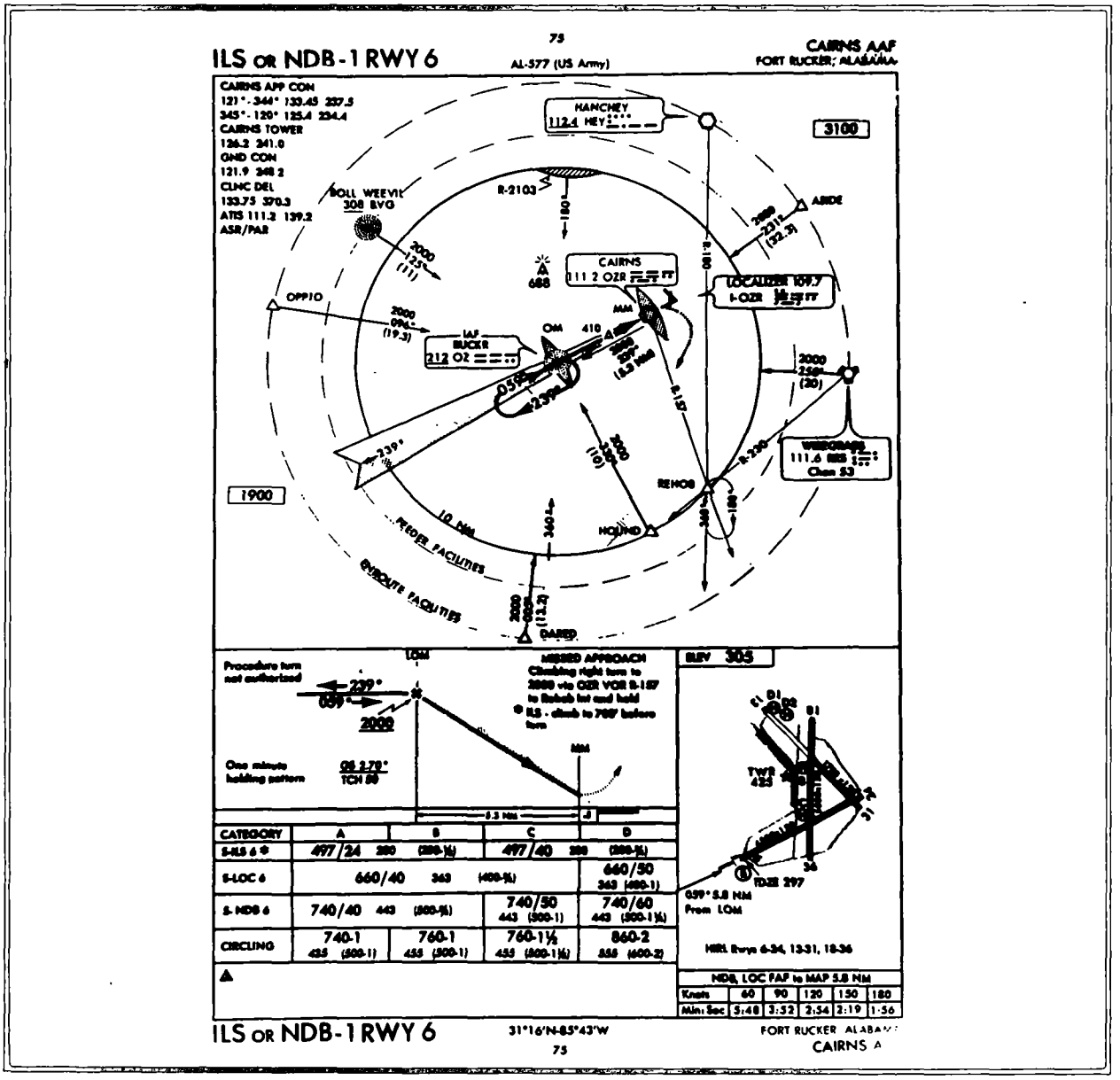


Figure 21-9. Typical approach chart.

to the frequency of the compass locator, providing that receiver is not required for other navigation. Tracking on the published feeder route should be started as soon as practicable after departing the enroute fix. While on the transition, the remaining navigation receivers should be tuned and placed in proper operation for the ILS approach. Passage of the LOM will be indicated by the ADF bearing pointer and by reception of the signal from the outer marker. If the ILS has been tuned, the course deviation indicator will move rapidly from one side to the other as the localizer course is crossed.

21 7. FRONT COURSE ILS APPROACH

After LOM passage, the aviator will turn outbound to parallel the localizer course (if a procedure turn barb is depicted on the localizer course) or make the proper holding pattern entry if a holding pattern is depicted and the procedure turn is not authorized. If a procedure turn is depicted, the aviator may descend to the procedure turn altitude; fly outbound the required time, depending on the winds and altitude to be lost, while remaining within the designated distance. Upon completion of the procedure turn by intercepting the localizer course, the aviator may descend to the altitude indicated for interception of the glide slope. If the aviator must start the approach from a depicted holding pattern, he will descend to the procedure turn altitude while flying the required holding pattern. Upon intercepting the approach course inbound, he may then descend to the minimum altitude that is to be used to intercept the glide slope. This will be below the glide slope. The final approach descent will begin when the aircraft intercepts the glide slope. The aviator should note the time of LOM passage. He can use this time to determine the missed approach point in the event reception of the glide slope is interrupted and the approach must be continued as a localizer approach. A missed approach will be initiated if, at the decision height, the runway approach threshold, approach lights, or other markings identifiable with the approach end of the runway are not clearly visible to the aviator. After the missed approach is satisfactorily initiated, the aviator should report that the approach has been missed, include the reason (unless initiated by ATC), and request clearance for specific action; i.e., to alternate airport, for another ILS approach, or a GCA (if minimums are lower).

21-8. LOCALIZER ONLY APPROACH

The localizer only approach is flown the same as the front course ILS approach with the following exceptions:

a. The minimum altitude to the FAF must be observed.

b. Timing for determination of the missed approach point should begin at the FAF.

c. Descent to minimum descent altitude (MDA) is initiated upon passing the LOM. The descent should be started without delay and continued at a rate that

will cause the aircraft to reach the MDA prior to the missed approach point (MAP). This will aid the aviator in arriving at the MDA with enough time/distance remaining to identify the runway environment and descend from MDA to touchdown at a normal rate for his aircraft.

d. The aviator uses the MDA for a localizer approach (fig 21-9), or for circling, according to the approach clearance received.

e. Missed approach is initiated when the computed time from the localizer FAF to missed approach point has elapsed and visual contact has not been established with the runway environment.

The localizer transmitter produces both a front course and a back course (fig 21-1). The back course is frequently used as an additional approach course (fig 21-10). Normally, a glide slope transmitter is not installed with the intent of radiating signals toward the localizer back course. Therefore, the back course approach is usually a nonprecision approach, and is flown in the same manner as the localizer only approach (para 21-8). A VOR radial or a marker beacon is usually used to establish the final approach fix. There is usually no approach lighting system associated with the back course approach, so visual contact with the runway environment may be more difficult than during a front course approach. The aviator must

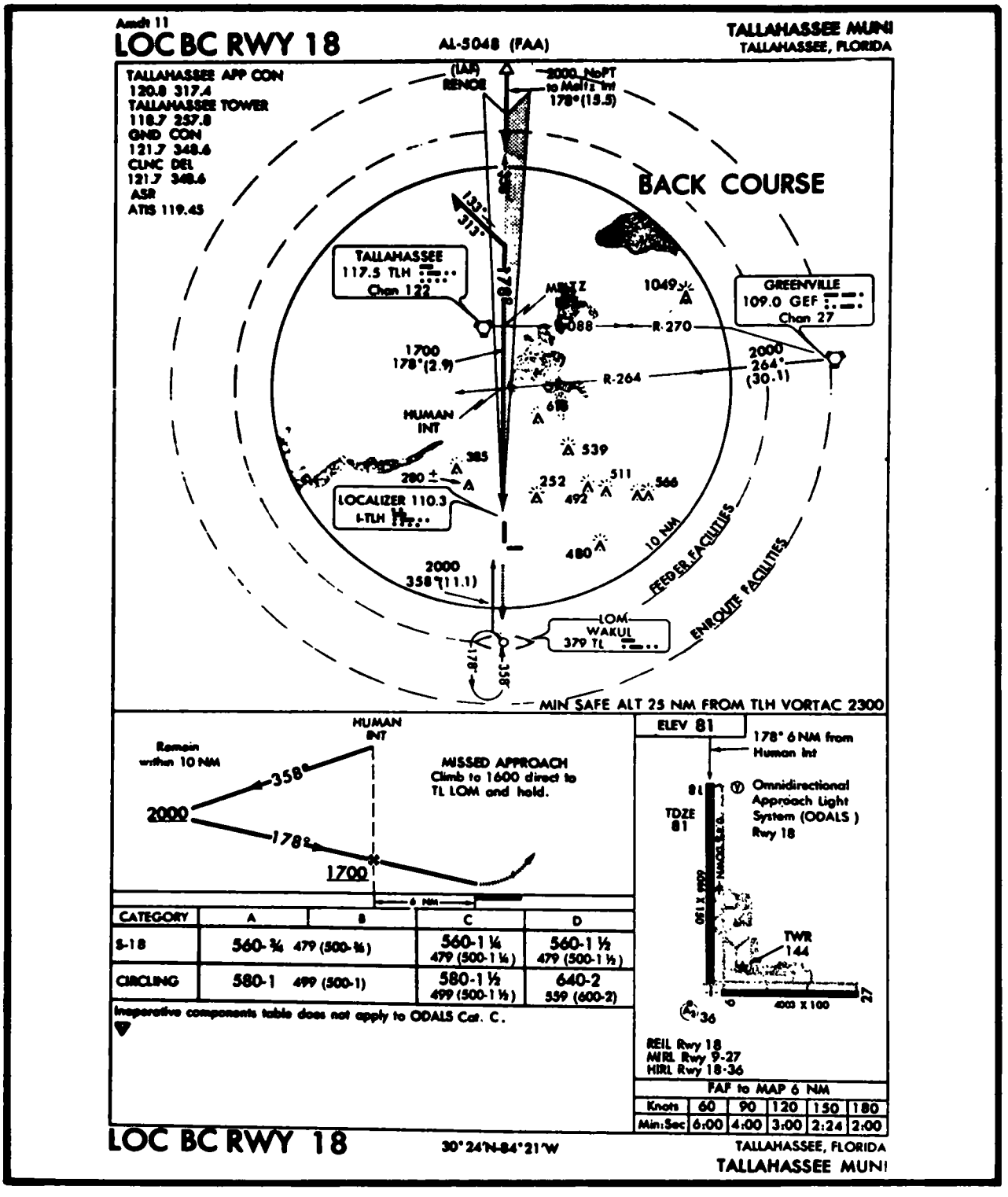


Figure 21-10. Back course ILS approach chart.

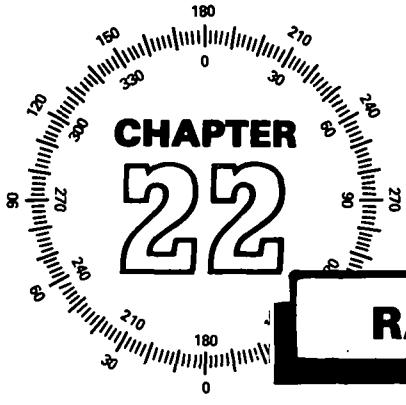
remember that the course deviation indicator is directional outbound and nondirectional inbound on the back course. When using a course indicator that has a heading pointer (fig 14-3), the published heading of the front course should be set in the course selector. The heading pointer will be in the bottom half of the course indicator when inbound on the back course. Turning to place it toward the course deviation indicator will then correct the aircraft toward the approach course.

21-10. RUNWAY VISUAL RANGE

Where available, runway visual range is the controlling visibility for straight-in landings from an instrument approach. Figure 21-11 shows the published DH and RVR for a straight-in ILS approach as being 207/24. This means that an RVR value of 2,400 feet is authorized as a minimum for beginning the approach. However, the aviator may not continue an approach below the DH (207) unless visual contact has been made with the runway environment. The aviator must be aware that the reported RVR may not be representative of the range at which he will sight the runway. In fact, the aviator's slant range visibility may be considerably less than the reported RVR. The nose of the aircraft, particularly if a nose high pitch attitude is being maintained, may also block out the sight of approach lights, terrain, and runway end environment. Knowledge of these various factors will aid the pilot in making a safe, smooth transition from instrument to visual flight for a landing.

CATEGORY	A	B	C	D
S-ILS-5	207/24 200 (200-½)			
S-LOC-5	360/24 353 (400-½)			
S-VOR	400/24 393 (400-½)			
CIRCLING	440-1 433 (500-1)	460-1 453 (500-1)	460-1½ 453 (500-1½)	560-2 553 (600-2)

Figure 21-11. Approach minimums based on RVR.



RADAR

Section I. AIR TRAFFIC CONTROL (ATC) RADAR

[redacted]

a. A great advantage of radar air traffic control over conventional (nonradar) control is that radar offers very precise data on aircraft location; consequently, the amount of separation required between aircraft can be greatly reduced by the use of radar.

b. Major air traffic control uses of radar include—

(1) Resolving enroute traffic conflicts and providing enroute traffic advisories.

(2) Expediting arrivals and departures in the terminal area.

(3) Controlling instrument approaches.

(4) Monitoring nonradar instrument approaches (instrument landing system (ILS), automatic direction finder (ADF), and VHF omnidirectional range (VOR)).

(5) Radar vectoring as a supplementary means of navigation to expedite traffic, to avoid traffic conflicts, or to avoid observed hazardous weather when possible.

(6) Providing limited radar weather information and radar weather advisories.

> *Caution*: **Pilots should use extreme caution when using airport surveillance radar (ASR) to avoid hazardous weather. ATC radar is not designed to show weather. In fact it has circuitry for eliminating weather presentations which interfere with the primary function, which is the observation of air traffic. See note following paragraph 22-17.**

c. Virtually all radar ATC relies on one of the types of surveillance radar discussed in paragraphs 22-2 and 22-3.

22-2. AIR ROUTE SURVEILLANCE RADAR (ARSR)

The use of long-range radar for control of traffic by the air route traffic control centers (ARTCC) is standard procedure. The range of this type of radar is approximately 200 nautical miles (NM), with altitude coverage to 40,000 feet. Since the area of control of an ARTCC normally is more than 200 NM, more than one radar is required to give complete coverage.

a. ARSR indicators normally are centrally located in the air traffic control center. However, the antennas are remotely located at outlying sites selected to produce the best radar coverage of the area. An outlying radar unit can serve two or more centers simultaneously.

b. Either transparent map overlays or electronically displayed video maps are normally used on the controller's scope to indicate the location of radio navigational aids (NAVAID), airways, and reporting points. In effect, the controller can see all of the air traffic within his area of responsibility.

22-3. AIRPORT SURVEILLANCE RADAR

The range of ASR is usually a 30-NM to 50-NM radius from the antenna site. An overlay on the scope or a video map (para 22-2b) shows facilities and landmarks in the area. The two basic purposes of ASR are (1) for radar approaches (para 22-9) and (2) for radar control of air traffic in the terminal area by approach control facilities.

Section II. RADAR AIR TRAFFIC CONTROL PROCEDURES

22-4. GENERAL

In this section various types of radar control services are discussed and the general principles involved in each are emphasized. For details of the techniques and procedures used by the radar controller, see FAA publication 7110.65.

22-5. IDENTIFICATION

a. All radar air traffic control services depend basically upon the positive identification of the aircraft target being controlled. Radar control is lost the moment identification is lost. The controller identifies a primary or radar beacon target by—

(1) Observing a departing aircraft target within 1 mile of the takeoff runway end.

(2) Observing a target whose position with respect to a fix corresponds with a direct position report received from an aircraft and the observed track is consistent with the reported heading or route of flight.

(3) Observing while a target makes an identifying turn(s) of 30° or more, provided both of the following conditions exist:

(a) Except in the case of a lost aircraft, a pilot position report is received which assures him that the aircraft is within radar coverage and within the area being displayed.

(b) Only one aircraft is observed making those turns.

(4) Receiving a coded transmission from a radar beacon transponder in the controlled aircraft (para 22-13).

b. If radar identification is lost, the radar controller immediately advises the aviator. If necessary, he then issues instructions and clearances to the aviator to permit resumption of conventional control.

22-6. TRANSFER OF RADAR CONTROL (HANDOFF)

Transfer of radar control (handoff) from one controller to another involves positive identification of the target aircraft by the receiving controller. Methods for transferring radar control are as follows:

a. The controller physically points out the target to the receiving controller.

b. The controller informs the receiving controller of the following:

(1) The distance and bearing of the target from a fix or transfer point shown on both radarscope displays.

(2) The observed tracks of the target, unless already known.

c. Radar beacon transponder is used (para 22-13).

22-7. ENROUTE CONTROL PROCEDURES

a. *Separation.* Within 40 NM of the radar site, aircraft under positive radar control are provided a minimum of 3 NM horizontal separation between all identified targets. If the controlled aircraft are more than 40 NM from the radar site, the required separation is 5 NM because target-distance-fixing capability is not as precise. At this distance, two targets which are close together (e.g., 3 NM) can appear as one on the radarscope. Aircraft normally are kept a minimum of 1.5 NM away from the boundary of adjacent airspace when less than 40 NM from the antenna. When 40 NM or more from the antenna, the minimum is 2.5 NM. Horizontal separation is provided between aircraft flying at the same altitudes. The radar controller has a number of different altitudes and flight levels under his jurisdiction. Separation can also be effected by assignment of different altitudes or flight levels.

b. *Routing.* Established airways are used by radar controllers for enroute traffic. However, if required minimums of separation and obstacle clearances are met, controllers may alleviate traffic conflicts by using radar vectors which depart from established routes. Aviators may request deviation from established routes to avoid hazardous weather conditions (para 22-16). When the controller vectors the aircraft off the assigned route, he will normally specify the point to which the vector will take the aircraft and the purpose of the vector. If communications fail, the aviator should proceed to the point specified.

c. *Altitude.* In some cases, enroute radar provides the controller with target altitude data; in other cases, the controller must rely on the aviator's reported altitude. In either case, altitude assignments are made in a manner similar to those of nonradar traffic control.

(1) In certain cases, the radar controller may assign an altitude below the minimum enroute altitude (MEA) for the airway. However, an altitude assignment below the minimum obstruction clearance altitude (MOCA) will not be made.

(2) If the controller assigns an altitude below the MEA, he will realize that the aircraft may be unable to navigate because of the possibility of passing below the minimum reception altitude of the radio facility. Therefore, the radar controller will navigate the controlled aircraft past all obstacles by offering the aviator radar vectoring service.

[redacted]

a. *Departures.* Wherever practicable, radar departure routes are established as *standard instrument departures* (SID). Channelized altitudes are placed under the

jurisdiction of radar departure control. The use of standard departure routes and altitudes reduces the amount of coordination between departure/arrival control and tower (local visual flight rules (VFR) control) facilities.

(1) Departure routes normally are based on the use of available radio facilities and do not require radar service for navigation. However, for an operational advantage, the controller may provide vectoring service for navigation; e.g., to achieve adequate separation, noise abatement, avoidance of hazardous weather, or for other reasons. If an aviator is given a radar departure which deviates from established SIDs or routes, he will be advised by the controller of the route or SID to which the aircraft is being vectored.

(2) Radar separation for departures is maintained as required by traffic conditions and within the saturation limits of the radar facility. Handoff to enroute radar or transition to nonradar separation is accomplished as traffic conditions permit. In all cases, the transition to nonradar separation is completed well within the limits of radar coverage.

b. *Arrivals.*

(1) Routing to nonradar facilities, such as ILS, ADF, and VOR, can be accomplished with radar control of arriving aircraft. Radar feeder routes may be established to "feed" the traffic to the final approach fixes (FAF) as required.

(a) A radar feeder route is similar to a conventional nonradar feeder route (chap 19). The nonradar feeder route is usually a straight course from an outer fix to an approach fix with bearing, distance, and minimum altitude published. However, a radar feeder route may employ several "legs" with different courses and different minimum altitudes on the legs. This multilegged route is also referred to as the *radar pattern* (random vectors). In some cases, it may resemble a conventional VFR traffic pattern with downwind and base legs.

(b) The radar feeder area and required obstacle clearance are different from those required for nonradar feeder routes. In general, radar feeder routes allow greater airspace use because (1) known obstacles can be plotted on the overlay map of the radarscope, and (2) identified aircraft targets can easily be provided with adequate obstacle clearance.

(c) Provided the radar controller complies with the minimum separation and obstacle clearance standards required by the air traffic control (ATC) procedures manual, he can vary radar traffic patterns to resolve conflicting traffic conditions. If a nonradar final approach is being used, the controller can use radar vectoring to the final approach course.

(2) If the final approach of the aircraft is to be controlled by radar (ground controlled approach (GCA)), the vectoring to the final approach course is the preliminary part of the GCA. The radar

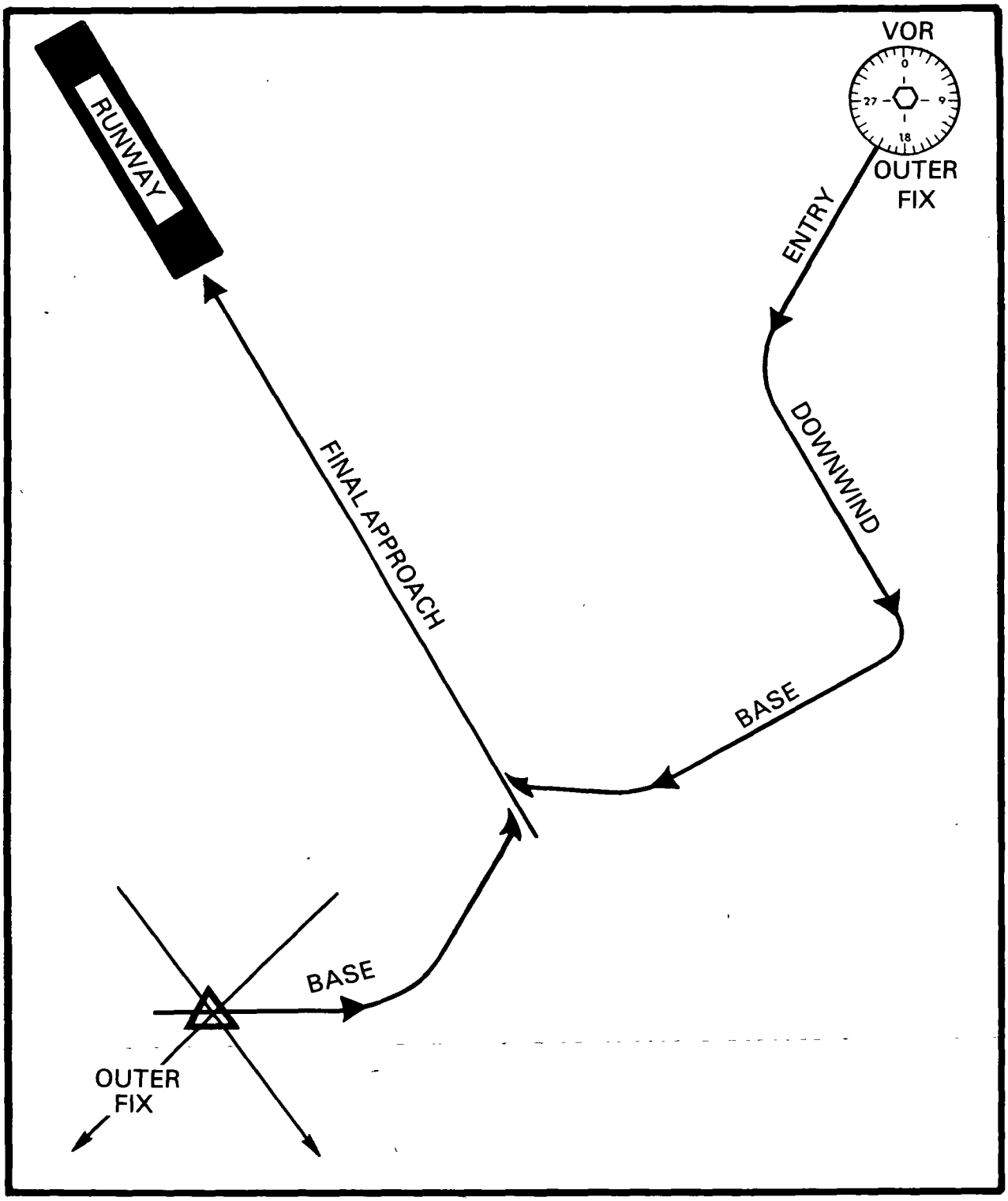


Figure 22-1. Radar patterns to GCA final approach.

pattern leading up to the final approach course can assume any configuration which takes into account the location of landing and navigation facilities, arrival routes, and the airport.

(a) The GCA final approach may be one of two types (para 22-9). However, the type used has little effect on the radar pattern leading to the final approach segment, except perhaps at the point where the final approach course is intercepted.

(b) Patterns are established from outer fixes to intercept the final approach course. For typical approach patterns, see figure 22-1. While the aircraft is in the radar pattern, prior to the time it is turned on final approach, the radar controller issues appropriate advisories to assure effective completion of the radar approach (para 22-9).

a. *General.* The two types of radar final approaches are *airport surveillance radar* and *precision approach radar.* The type employed depends on the equipment available, landing runway, weather, and traffic conditions. ASR equipment provides the controller with positive data on range and azimuth of the aircraft target. However, with PAR equipment available, the final approach can be more precisely controlled. To the controller, the basic advantages of PAR are that he can determine the exact aircraft position in relation to the glidepath, and the range and azimuth can be determined with greater accuracy. In general, where PAR is employed, approach minimums are lower.

b. *Approach Information:* Unless the aviator states that he has received the automatic terminal information service (ATIS) broadcast, the controller will issue the following information.

(1) Altimeter setting.

(2) Ceiling and visibility if ceiling at the airport of intended landing is reported below 1,000 feet or below the highest circling minimum, whichever is greater, or if the visibility is less than 3 miles.

(3) Any special weather observations.

(4) Pertinent information on known airport conditions if they are considered necessary to the safe operation of the aircraft concerned.

(5) Lost communications procedures may be—

(a) Required if weather is as stated (para (2) above).

(b) For training purposes.

c. *Before Starting Final Approach.* The controller will issue the following information:

(1) Type of approach and runway to which the approach will be made.

(2) Aircraft position at least once. In addition, he will advise the aviator to perform landing check.

d. *Final Approach—ASR.* On final approach, the aviator will be given the frequency and told to contact the final controller. The final controller will make a radio check with the aviator and then advise him not to acknowledge further transmissions. Heading corrections will be issued as required to keep the aircraft on the final approach course. The controller must transmit at least once every 15 seconds or the aviator will assume that he has lost communications with the controller. If a full stop landing is to be made and any portion of the final approach conducted under instrument flight rules (IFR) conditions, a wheels-down check will be made and the missed approach instructions issued. Advance notice of where the descent will begin and the straight-in minimum descent altitude (MDA) will be furnished. When the aircraft reaches the descent point, the controller will instruct him to descend to the MDA. Course guidance and distance from the runway, airport, or missed approach point (MAP) will be furnished on the remainder of the approach. When approach guidance is discontinued, the aviator will be advised of his position and instructed to execute a missed approach unless the runway approach or runway lights or airport is in sight.

e. *Final Approach—PAR.* After being turned on final, the transfer to final controller, final controller radio check, and course guidance will be issued as in ASR final approach except that the controller must transmit at least once each 5 seconds. The wheels-down check will be made and missed approach instructions issued if required ("d" above). Approximately 10 to 30 seconds before final descent, the aviator will be informed that he is approaching the glidepath. The decision height will be issued only if requested by the aviator. At the point where final descent is to start, the aviator will be instructed to begin descent. Glidepath and course information and distance from runway will be issued until the aircraft is over the landing threshold. The aviator will be informed when he is at decision height.

f. *No Gyro Radar Approaches.* These approaches, ASR or PAR, will be flown as outlined above, except the controller will issue instructions as to when to start and stop the turns (headings will not be issued), and when to make half-standard rate turns on the final approach.

[redacted]

a. If the PAR final approach course coincides with the NAVAID final approach from the FAF to the runway and one of the following conditions exists, aircraft conducting precision or nonprecision approaches will be monitored by PAR:

(1) The reported weather is below basic VFR minima.

(2) Nighttime.

(3) Request of the pilot.

b. Surveillance radar will not be used to monitor nonradar approaches.

c. The controller will inform the aviator that his approach will be monitored and state the frequency to be used if it is not the same as the communications frequency used for the approach. In addition, he will—

(1) Advise the aviator executing a nonprecision approach that glidepath advisories are not provided.

(2) Inform the aviator when he is passing the final approach fix.

(3) Advise the aviator when his aircraft goes well above or below the glidepath, well left or right of the course, and whenever it exceeds the radar safety limits. These will be repeated if no correction is observed.

(4) If after repeated advisories the aircraft is observed proceeding outside the safety limits or a radical target deviation is observed, advise the aviator that if he is unable to proceed visually, to make a missed approach.

[illegible] RADAR SERVICE [illegible] TRAFFIC

As IFR traffic volume and radar capability permit, future radar service will increase assistance to VFR traffic. As more airports and control centers become equipped with modern radar, this expanded service will become widespread. For the types of service and the existing procedures to employ them, see current navigation publications. Among these services to VFR traffic are the following:

a. Sequencing of arriving traffic.

b. Traffic advisories.

c. Weather advisories.

[illegible] ASSISTANCE WITHIN [illegible] IDENTIFICATION [illegible]

a. Radar assistance is available on a 24-hour basis to all identified aircraft within the limits of any Air Defense Identification Zone.

b. The following services will be provided when and where military commitments permit, but no responsibility for direct control of aircraft is accepted.

(1) Track and groundspeed checks.

(2) Position of aircraft in latitude and longitude or by bearing and distance from a known point.

(3) Magnetic heading to steer and distance to the nearest aerodrome or other designated points.

(4) Position of heavy cloud in relation to the aircraft.

c. Procedures to be followed are—

(1) Use frequency 122.2.

(2) Call "Radar Assistance." The subsequent call sign of the ground station will be given by that station.

(3) Request service desired.

(4) Make initial contact at the highest practicable altitude.

d. The radar assistance is advisory only and does not absolve the aircraft commander of the responsibility for safe navigation of his aircraft and compliance with ATC clearances or other required procedures.

e. If commitments preclude granting of assistance, the ground station will transmit the word "unable." No further explanation will be given.

f. All speeds are given in knots, all distances in nautical miles, and all bearings or headings in degrees magnetic.

Note. Canadian military assistance provides bearing in degrees true.

Section III. TRANSPONDER OPERATIONS

[redacted]

a. There are two basic types of airborne transponders having select code capability on mode 3. One has a 64-code, two-digit select capability and the other has a 4,096-code, four-digit select capability. Both types are compatible with and responsive to ATC ground interrogation equipment. The basic operational difference is that the 64 select code transponder transmits only the first two digits of the 4,096 select code scale.

b. When filing a domestic IFR flight plan (DD Form 175 or equivalent), pilots will indicate the radar beacon transponder

or special navigation equipment capability or limitation by adding a slant (/) and the appropriate symbol immediately following the aircraft designation, i.e., CH-47/T, T-42/A, etc. Refer to the *Airman's Information Manual* or flight information publication (FLIP) to find appropriate code letters.

c. Transponders will be operated in "STBY" while taxiing for takeoff and "OFF" after landing.

d. In order to standardize the system, ATC personnel will use a four-digit code designation when assigning codes. When a four-digit code is assigned to an aircraft which has only a 64-code, two-digit capability, only the first two digits are used. Example: Code 2100—use code 21; code 0700—use code 07; etc.

Note. **Pilots should be careful not to reply on any code not specifically assigned by a controller. To do so could result in erroneous target information on the controller's scope.**

e. For operation of the transponder, see operator's manual for appropriate aircraft.

22-14. PHRASEOLOGY

Radar beacon code word phraseologies used by ATC controllers in air-to-ground communications and expected pilot action under specified conditions are as follows:

a. SQUAWK (number)—Operate transponder on designated code in mode 3.

b. IDENT—Activate appropriate IDENT control.

c. SQUAWK (number) AND IDENT—Operate transponder on designated code in mode 3 and activate appropriate IDENT control.

d. SQUAWK STANDBY—Switch transponder to "STBY" position.

e. SQUAWK LOW/NORMAL—Operate sensitivity as directed. Transponder is operated in "NORMAL" position unless ATC specifies "LOW."

f. SQUAWK ALTITUDE—Activate mode C with automatic altitude reporting.

g. STOP ALTITUDE SQUAWK—Turn off altitude reporting switch and continue transmitting mode C framing pulses. If your equipment does not have this capability, turn off mode C.

h. STOP SQUAWK (mode in use)—Switch off designated mode.

i. STOP SQUAWK—Switch off transponder. (STANDBY recommended.)

j. SQUAWK MAYDAY—Operate transponder in the "EMERGENCY" position—mode 3, code 7700.

k. SQUAWK VFR—Operate transponder on code 1200 or as assigned by ATC.

Section IV. GROUND WEATHER RADAR

[redacted]

In addition to traffic control, there are other applications of radar which contribute to efficient aviation operations. The National Weather Service, the United States Air Force (USAF), and United States Navy (USN) operate radar storm detection sites. Some ARTC centers have access to radar sets designed for weather observation. As a result of these efforts, a large part of the continental United States and some oversea areas provide radar weather service.

[redacted]

Direct communication service between aviators and forecasters or observers is provided at many locations by the USAF. At locations where the service is available, the aviator can call Metro on a specified frequency. The forecaster or observer will reply to the call and can furnish the aviator an in-flight weather advisory by a qualified weather forecaster or observer who has access to weather radar coverage of the flight area. While operating on an IFR flight plan, the aviator must obtain permission from the controller to leave the control frequency long enough to obtain a weather advisory. Subsequent vectoring, which may be necessary to avoid hazardous storm areas, can be coordinated between observer or forecaster, aviator, and controller. For Metro service listings and frequencies, consult current navigation publications.

22-17. FEDERAL AVIATION ADMINISTRATION (FAA) WEATHER RADAR ADVISORIES

In some cases, FAA facilities obtain weather information from weather radar sets of the individual facility and relay this information to the control center or flight service station (FSS) for broadcast to aviators as a weather advisory. In other cases, the traffic controller's facility may have a weather radar set, or the controller may issue a weather advisory to the aviator based on weather data obtained from the air traffic control radar set.

Note. **Traffic control radar sets, however, deemphasize weather phenomena since the image of storm areas and precipitation tends to obscure aircraft targets; consequently, the sets are designed to "filter out" echoes from storms and precipitation. The resulting display on these sets thus does not portray, in great detail, the existing weather phenomena; therefore, the aviator should obtain weather data from a weather radar source if possible.**

CHAPTER 23

TACTICAL INSTRUMENT FLIGHT

Section I. GENERAL

23-1. PURPOSE AND SCOPE

The purpose of this chapter is to provide information for training rotary wing aviators in tactical instrument flight. Discussed within this chapter are the considerations for employment of tactical instrument flight, procedures for construction of tactical instrument airways and safety zones, and a recommended program of instruction (POI) for tactical instrument flight training.

23-2. PREREQUISITES

This chapter does not address specifics about airspace management, instrument flying, navigational procedures, map-reading, and instrument flight techniques. It is understood that the aviator is knowledgeable in these subjects prior to being trained in tactical instrument flight. If, however, additional training is required in these areas of concern, refer to FM 1-60, *Airspace Management and Army Air Traffic in the Combat Zone;* FM 21-26, *Map Reading;* and previous chapters of this publication. The aviator should be instrument qualified and proficient before undergoing tactical instrument flight training.

[redacted]

a. To perform tactical instrument flight safely, you must have a thorough knowledge of the enemy situation and air defense (AD) capability. With this information and a knowledge of where and when a covering force is employed, an enroute course and flight altitude can be planned which may decrease the vulnerability of the aircraft to Threat weapons. The degree of vulnerability that remains after applying the procedures contained herein must be taken into consideration before conducting instrument flight in a high threat environment. You must also be aware that a friendly threat exists over the battlefield. Unless the proper identification, friend or foe (radar) (IFF) code and flight corridors are used, there is a danger of being destroyed by friendly AD weapons.

b. Additionally, you must recognize the enemy's electronic warfare (EW) capability. This threat may be used to degrade the radio signal of the navigational aids (NAVAID) or increase the enemy's threat acquisition capability. The success you achieve on the battlefield will be dependent upon how you learn to cope with the enemy threat. You must use every means to avoid, suppress, or destroy the enemy AD and EW systems. FM 90-1, *Employment of Army Aviation Units in a High Threat Environment,* and FM 1-88, *Aviator's Recognition Manual,* are two publications that identify the threat you may encounter on the high threat battlefield.

Section II. TACTICAL EMPLOYMENT CONSIDERATIONS

[redacted]

To provide round-the-clock aviation support, aviation units must be capable of performing tactical instrument flight in areas where terrain flight cannot be performed due to meteorological conditions. Presented within this section is a discussion of the definition of tactical instrument flight, training requirements, and the principles of employment in a high threat environment. A knowledge of this information is essential to insure everyone involved performs their duties in an effective manner.

[redacted]

Tactical instrument flight will only be performed when meteorological conditions at origin or en route preclude nap-of-the-earth (NOE) flight.

Tactical instrument flight is defined as "flight under instrument meteorological conditions (IMC) in an area directly affected by the Threat." It is used as a means to complete an assigned mission that is critical in nature when meteorological conditions at origin or en route preclude

NOE flight. Tactical situations can be expected which require single-ship operations to be conducted within the threat environment during IMC. In order to survive during such missions, aviation units must operate under instrument conditions at altitudes well below the altitudes specified in civil instrument flight rules (IFR). While standard civil rules may be compatible with threat conditions in rear areas, they will be inadequate for foward areas. Tactical instrument flight provides the means to insure maximum support of ground tactical units by allowing aircraft to move about the battlefield even in adverse weather under high threat conditions. Survivability will require techniques which go beyond the use of today's conventional airways and NAVAIDs. Sophisticated approach procedures and equipment will not be available. Instead, instrument flight will be performed under marginal conditions requiring the highest level of aviator proficiency rather than equipment. Aircraft will operate routinely at reduced altitudes with minimum navigational aids and minimum air traffic control (ATC) facilities and regulations. Increased dependence on preflight planning and aircrew proficiency will be essential to accomplish the mission using the tactical instrument mode of flight.

Threat weapons dictate where tactical instrument flight will be performed.

23-6. TRAINING

Tactical instrument flight can be successfully accomplished through diligent and thorough training of aircrews, air traffic management, and pathfinder personnel. Through testing, training, and practice, the capability can become a reality. Tactical instrument flight training not only should familiarize aviators with the principles and employment of tactical instrument flight in the high threat environment, it must teach them to execute an instrument flight and approach into a landing zone (LZ) using minimum electronic communication and navigation devices with confidence. Unit training must be oriented toward accomplishment of the unit's mission under adverse weather and threat conditions with a minimum of assistance from electronic communication and navigation devices. Air traffic management and pathfinder personnel, as well as aircrews, also must be integrated into the training. Units must incorporate tactical instrument functions into their everyday missions. Flying at lower altitudes, minimal use of available navigation and communication equipment, detailed premission planning, and postmission debriefing are training practices that can be used on a routine basis during normal operations. Training must emphasize flexibility in order for aviation elements to be able to respond quickly and reliably in a wide range of adverse weather situations.

23-7. PRINCIPLES OF EMPLOYMENT

Because tactical instrument flight is performed under marginal conditions, greater responsibility is placed upon the aviator for planning and flight-following. When operating under Federal Aviation Administration (FAA) control, you are issued low altitude enroute charts. These charts identify the location of NAVAIDs, headings, and altitudes. Also, the flight-following procedures are identified in Army regulations (AR) and publications. When

performing tactical instrument flight, you must determine all this information. The principles listed below must be considered in planning and conducting tactical instrument flight.

a. *Threat Avoidance.* To minimize the vulnerability of the aircraft to Threat weapons, tactical instrument flight can best be accomplished when enemy forces are conducting retrograde operations or when friendly covering forces are deployed forward of the forward edge of the battle area (FEBA). The width and depth of a penetration by friendly forces will determine how far forward tactical instrument flight can be performed safely. The distance the covering force is deployed forward of the FEBA will also affect the distance Threat weapons can engage aircraft operating in friendly airspace. Normally, antiaircraft artillery weapons cannot engage aircraft along the FEBA when the covering force is deployed; however, detection by the weapons system is possible. The primary threat to aircraft conducting tactial instrument flight in the area along the FEBA will be the air defense missile. To degrade the effectiveness of these weapons, suppression to include radio jamming, artillery fires, and chaff should be used when the mission is being flown.

b. *Flight Clearance and Flight-Following Procedures.* Whenever tactical instrument flight is planned, you must know the ATC procedures to be followed. The procedures to be used will be determined by the area in which the flight is conducted and whether communications can be established with an ATC facility. The following are examples depicting specific areas and flight-following procedures. The purpose of each procedure is to maintain effective control of the airspace over the battlefield; however, the control measures must not cause delays in mission employment and must not restrict the movement of aircraft about the battlefield.

(1) *Rear area to tactical operations area.* When flying from a rear area to a tactical operations area, maintain contact with the ATC facility as long as possible and then assume responsibility for making contact with other tactical forward units for flight-following.

Air traffic control procedures are determined by your location on the battlefield.

(2) *Tactical operations area to rear area.* You serve as your own initial clearance authority and attempt to make contact with ATC elements en route. The flight should follow closely the previously planned and coordinated flight plan.

(3) *Flight initiated from unit heliport or airfield.*

(a) Clearance for tactical instrument flights is secured from the division Flight Coordination Center (FCC) element through the company operations prior to takeoff if communications exist.

(b) When radio contact is not possible or feasible, contact the ATC elements by landline for flight filing and clearance prior to takeoff.

(4) *Flight originating from a tactical site.*

(a) In the event tactical instrument flight is required from a forward tactical location, such as a forward arming and refueling point (FARP), and communications cannot be established with an ATC facility, you must serve as your own initial clearance authority.

(b) As soon as practical after the flight is initiated, you should attempt to establish radio contact with an ATC element or a ground tactical unit to relay the flight plan. You should follow the original tactical instrument plan as closely as possible until either direct contact with an ATC element is made or a ground unit relay is established.

(5) *In-flight transition from terrain flying to tactical instrument flight.* When the tactical mission requires the transition from visual meteorological conditions (VMC) to tactical instrument flight, you must carefully analyze your map to select a route and altitude to provide obstacle and terrain avoidance.

(a) When communication with an ATC element is not possible, you serve as your own clearance authority until direct communication with an ATC element is made or contact with a ground unit relay is effected.

(b) Where communication with an ATC element is possible, report location and intended flight plan. Maintain direct ATC communications as long as possible until flight termination. If enroute communication is lost, follow the reported flight plan as closely as possible until contact is regained—either direct or through a relay—or the flight is terminated. If communications with an ATC element cannot be reestablished, flight-follow with a ground tactical unit.

(6) *Flight in a severe EW threat or radio silence environment.*

(a) Of necessity, much of tactical flight will be conducted in a severe EW threat environment. To avoid electronic detection in forward areas, NAVAIDs must be restricted to operation only when they are to be used, and then only intermittently. In order to avoid detection and destruction, the electronic signature of NAVAIDs and aircraft must be kept to a minimum, thereby making radio silence a requisite for mission accomplishment.

(b) You should use landline communications when available for coordinating and clearing tactical instrument flights with an ATC element prior to takeoff. If landline communication is not possible, use secure radio channels. Close initial coordination with the ATC element is essential prior to initiating the flight to eliminate unnecessary radio communications during flight.

(c) During a radio silence environment, voice radio communication for navigation and flight-following is not possible. You must coordinate in detail prior to takeoff, when possible; serve as your own clearance authority during in-flight transitions from VMC to tactical instrument flight; and often operate a flight-following facility or unit while en route.

23-8. FLIGHT ALTITUDES

Flight altitude is determined by the height of terrain obstructions and the availability of terrain for masking.

Flight altitudes will be dictated by the enemy air defense threat. The limits will be *less than those* specified in AR 95-1 and may be as close to the ground as the terrain obstacles permit. Figure 23-1 shows an example of how the AD threat will appear on the modern battlefield. The illustration graphically shows the relationship of standard instrument flight and tactical instrument flight to the AD threat and terrain obstacle clearance considerations. The overriding concern in tactical instrument flight is to remain below the enemy air defense threat and continue to maintain a safe altitude above terrain obstacles in order to complete the mission. You can use instrument meteorological conditions and procedures in rear areas where the *effective range of the enemy air defense missiles* and other weapons are not a threat; however, you may be within the range of the enemy *early warning and tracking radar.* It is important that you are aware that the aircraft is within the radar range even though you are still outside the *effective range of the enemy air defense missiles* and other weapons. Although you may be beyond the

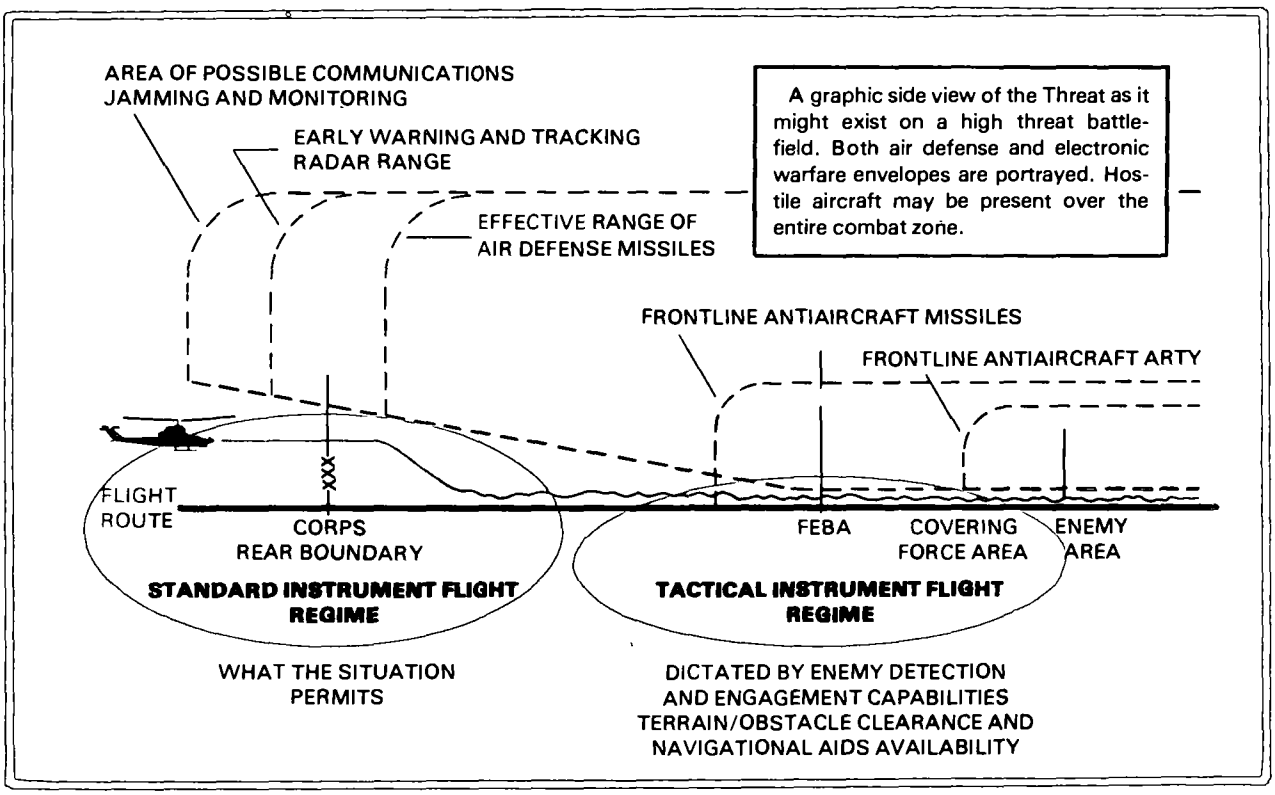


Figure 23-1. Threat profile.

range of ground-based weapons, you may be engaged by enemy aircraft.

a. As you continue to move forward toward the FEBA, you will come within the *effective range of the air defense weapons.* At this point, you must remain low enough to avoid acquisition by the early warning and tracking radar. In doing so, you must reduce the flight altitude to a level below the enemy threat, yet high enough to provide a safe clearance of terrain obstacles. As you fly toward the FEBA, the capability of the enemy radar to acquire the aircraft will continue to increase even at lower levels. You must continue to adjust the flight altitude and route accordingly to remain below this threat or to be masked by the terrain.

b. Upon reaching the forward area or the destination point, you will use a tactical instrument beacon to make the approach if visual flight conditions are not encountered. If visual conditions are encountered at the destination, or while en route, descend to terrain flight altitude and continue the mission.

c. Conversely, as you fly from a forward location toward the rear of the battlefield, you can progressively increase the flight altitude. A unit's forward or rear boundaries cannot be used as a reliable indication of the altitude to be flown to avoid the enemy air defense threat because these boundaries are highly mobile; are not always the same distance from the FEBA; or subject to the same terrain formations. The unit boundaries depicted on figure 23-1 are presented only to show how the threat will increase as the aviator flies nearer the FEBA and is forced to select lower flight altitudes. Each mission requiring the use of tactical instrument flight must be individually planned and an appropriate altitude profile planned to remain clear of both the threat and terrain obstacles.

23-9. FLIGHT ROUTES

Flight routes will be determined by availability of NAVAIDs.

The threat, terrain, weather, and availability of radio beacons all affect route selection. Considerations for each factor essential in establishing tactical instrument flight routes include the following:

a. Straight-line flight between takeoff point and destination will be precluded in many instances by both the terrain and the enemy air defense threat. In selecting the flight route, you must carefully analyze the threat as it affects potential flight routes. In most instances, the threat will be the overriding factor in selecting flight routes. You must make a thorough map reconnaissance of the possible route to the destination and return to determine the best route which will provide threat avoidance and terrain obstacle clearance. In tactical instrument flight, terrain obstacles can serve as valuable assets to deny enemy electronic detection just as they are used for concealment and masking during visual terrain flying in forward areas of the battlefield.

b. The availability and location of navigational aids are significant factors in

route selection. Regardless of what the weather condition may be, you should know the location and availability of the NAVAIDs within your area of operation. NAVAIDs in the rear area will be more widely spaced because the radio signal range can be received at a greater range due to the higher altitude the aircraft is flown in this area. NAVAIDs must be placed closer together in the forward areas due to the limited range the radio signal can be received at low altitudes. Route selection in the forward area will be restricted because of the reduced range of the beacons and limited number of beacons. To increase the unit's capability to conduct tactical instrument flight, NAVAIDs must be mobile and highly responsive. Routinely, they must be capable of rapid displacement on short notice. Air traffic management personnel can expect to move their equipment as frequently as every 4 hours to avoid enemy electronic detection and to prevent repeated use of the same airspace.

c. The enemy will employ highly sophisticated electronic warfare systems. Defeating this capability and protecting aviation assets will require maximum tactical ingenuity and resourcefulness. One of the most effective tactics will be to keep radio communications to the minimum. In selecting a route, communications security and a capability for maintaining communications should be prime considerations. Using terrain to mask the aircraft from possible acquisition by the enemy, early warning radar may also mask the aircraft from NAVAIDs and from communications with friendly units. Routes should be selected which provide reliable communications whenever feasible considering also the threat and the terrain.

(1) *Approaches.* Tactical instrument flight approaches will vary according to the area where the approach is to be performed. In rear areas where standard instrument flight procedures may be followed, ground-controlled approach (GCA) radar can be used for instrument approaches. Approaches in forward battle areas will be limited to using nondirectional beacons. The altitude to which descent can be made will depend on factors such as crew proficiency, aircraft instrumentation, approach NAVAIDs, terrain, and visibility. The ultimate goal of an approach is to allow the aircraft to descend through restrictive weather conditions to an altitude where conditions exist that will permit mission accomplishment. Tactical instrument flight approaches may be classified according to facilities as follows:

(a) Class I—Approach using ground-controlled approach or a derivative of the national microwave landing system with its distance-measuring equipment (DME). Guidance to 100 feet above ground level (AGL) is reliable for properly trained aviators in appropriately instrumented aircraft and air traffic management personnel trained in installation and operation of the equipment.

(b) Class II—Approach using one of the following: An instrument landing system (ILS), an area surveillance radar, or a nondirectional beacon. Centerline guidance is reliable with a positive position indication (fix) prior to start of letdown. Descent to 200 feet AGL is allowed for properly trained air traffic management personnel and aviators using appropriately instrumented helicopters. Visibility must be such that aviators can proceed visually following the approach.

(c) Class III—Approach using frequency-modulated (FM) homer.

Reliability of directional guidance and station-passage indication close to station is questionable. Descent altitude is dependent on terrain, and visibility conditions must be such that aviators can operate visually before touching down or continuing the mission. Aviators and air traffic management personnel must be highly proficient.

(2) *Navigational aids.* Because of the threat in forward areas of the battlefield, it will not be possible to operate NAVAIDs full time. Operating nondirectional beacons and surveillance radar NAVAIDs full time risks enemy acquisition of both the NAVAID and the aircraft as targets, or of having the enemy disrupt the mission by jamming the NAVAID signal. In rear areas where more sophisticated NAVAIDs can be used along with standard IFR, efforts should also be made to limit the signal transmission time to only those times when needed as an aid. In the forward battle areas, radio beacons should be operated in the low power mode and turned on intermittently or only upon request. This procedure lessens the chance of enemy detection.

(a) The portable radio beacon set AN/TRN-30(EX-1)V is currently used by field units. It transmits a radio signal that can be used in conjunction with the automatic direction finder (ADF) sets AN/ARN-59 and AN/ARN-83 installed in most Army helicopters. The radio beacon set provides an amplitude-modulated (AM) radio frequency signal on any one of 964 channels in the frequency range from 200 kilohertz (kHz) to 535.5 kHz and 1605 kHz to 1750.5 kHz in tunable increments of 500 hertz (Hz). The beacon can be operated in either of three modes—pathfinder, tactical, or semi-fixed. The range of the beacon depends upon the wattage and configuration of its operation. The capabilities of the radio beacon for each mode of operation are shown below.

CAPABILITIES	MODE OF OPERATION		
	PATHFINDER MODE (V_1)	TACTICAL MODE (V_2)	SEMI-FIXED MODE
Frequency Range	200-535.5 kHz 1605-1750.5 kHz	200-535 kHz	200-535 kHz
Range (km) Below 500 ft AHO	15 km w/15 ft. Mast Antenna		
Range (km) Above 500 ft AHO	25 km w/Whip Antenna 40 km w/30 ft. Mast Antenna	85 km w/60ft Mast Antenna	180 km w/60 ft Mast Antenna
Power Output	25W	60W	180W
Weight	39 lbs.	175 lbs	175 lbs
Channels	964	672	672
Power Source	6V Battery or Jeep Battery (26V)	Jeep Battery (26V)	Jeep Battery (26V)

WARNING: Mode (V_1) 200-535.5 KHZ use 30 ft. mast only.

(b) FM homing can be used for short distances as an emergency tactical instrument navigational aid when the onboard ADF equipment malfunctions or the ground-based nondirectional beacon becomes unreliable or inoperative. FM homing should be used only as backup NAVAID to return the aircraft to VMC or to a rear area.

(c) Tactical instrument flight at night is conducted primarily in the same manner as it is conducted in the day. However, during transition from tactical instrument flight to visual flight at the point of letdown, a light source must be present to provide a visual reference point landing. The lighted "T," "Y," or reference symbol may be used. If the landing site is located at a location other than the letdown point, a second light source to assist in landing is also necessary.

Section III. TACTICAL INSTRUMENT FLIGHT PLANNING

23-10. INTRODUCTION

The situation requiring an aviation support mission to be flown using tactical instrument procedures will be the most demanding you can imagine. To perform this mission while minimizing the exposure of the aircraft to Threat weapons and avoidance of terrain features and obstacles, you must plan the mission in great detail and your flight maneuvers must be very precise. This section discusses the planning considerations and explains the procedures for determining the minimum enroute altitude (MEA), the takeoff and climb requirements, the tactical instrument approach, the holding pattern, missed approach procedures, and emergency procedures for tactical instrument flight.

23-11. PREFLIGHT PLANNING

Prior to actual weather conditions requiring tactical instrument flight, you should have completed a portion of the preflight planning procedure. You may not know where the mission is to be flown; however, tactical instrument preplanned routes within the division forward area can be established based on the known location of the radio beacons. When the actual mission is received, an additional leg or legs can be added to the preplanned route. By developing preplanned routes, the time required to complete the preflight planning is reduced and less time is required to respond to a mission request.

a. Because the electronic emission of the radio beacons can be easily located by the enemy, they will operate at specified times or as needed and will be frequently relocated. Each time they are moved, you should construct new tactical instrument preplanned routes.

b. There is no existing document that provides information as to the location, frequency, or date-time group for relocation of the radio beacon. It is proposed that this information be contained in the

Communications-Electronic Operation Instructions (CEOI).

c. Although it is the responsibility of the aviator to compute the information required for tactical instrument flight, flight operations personnel should routinely develop tactical instrument preplanned maps. These maps should be available to the aviator upon receipt of an aviation support mission.

d. When planning for a mission requiring tactical instrument flight, you should follow a checklist to insure completeness. The following factors are essential preflight planning considerations:

(1) *Mission requirements.* When the mission to conduct a tactical instrument flight is received, you can finalize the premission planning that has already been performed. The following factors should be identified in the mission request:

(a) *What.* The nature of the aviation support mission; e.g., medical evacuation, resupply, must be identified. Also, the number or weight of material to be transported must be known.

(b) *Where.* The location of the pickup and dropoff point must be identified. This information is required to determine the enroute course to the dropoff point and to compute the enroute time and fuel requirement.

(c) *When.* Once it is known when the mission is to be performed, you can use the backward planning sequence to determine the takeoff time and when NAVAIDs should be turned on.

(d) *Who.* The unit being supported must be known. Coordination is required to insure the success of the mission.

(2) *Enemy situation.* You should know the location of friendly and enemy forces and their posture. To gain this information, study the unit's tactical map or contact the supported unit for detailed information concerning the tactical situation.

(3) *Threat air defense weapons.* It is important that the unit operations personnel obtain all available information which identifies the location of enemy air defense weapons. These locations should be plotted on the tactical situation map for review by the aircrews. Intelligence information on the enemy's tactical air capability must also be made available. Based on the Threat and route of flight, consideration should be given to requesting suppression of Threat weapons.

(4) *Friendly air defense weapons.* It is important that unit operations personnel obtain the locations of friendly air defense weapons and that these locations are plotted on the tactical situation map for review by the aircrews. Pilots must attempt, whenever possible, to avoid flying routes over or near friendly AD unit locations, to minimize the

possibility of friendly AD engagement. When it is not possible to avoid flying such routes, coordination as to flight routes and times must be made between the aviation element and the Army air defense element located at the division airspace management element, G-3. In either case, coordination must be made with the division airspace management element to insure that areas coincident with AD weapon locations have not been declared *restricted flight areas.*

(5) *Weather.* An in-depth weather briefing is desirable in determining mission feasibility. Enroute weather and destination weather at all intended points of landing should be acquired. Pilot reports (PIREP) are helpful when available. The US Air Force weather service provides a valuable source of weather information, especially in forecasting area trends and changes. Whenever possible, contact should be attempted with destination units to further enhance the accuracy of overall weather factors for the proposed mission.

(6) *Communications.* The frequencies and call signs of the supported unit, ATC facility and artillery units must be known. A current CEOI should be available, and you must be knowledgeable concerning its use.

(7) *NAVAIDs.* You must know the location of the radio beacon, its frequency, and when and where it will be relocated. Other information includes the FM radio frequency of the pathfinder operating the beacon and any known dead spots created by terrain features.

(8) *Special equipment.* The mission to be performed will dictate what special equipment will be carried aboard the aircraft; e.g., litter, tiedowns, night vision goggles. Survival equipment for the type of environment should be carried aboard the aircraft.

23-12. DETERMINING THE COURSE LINE

As information pertaining to the location of NAVAIDs and the supported units becomes available, you should plot it on your tactical map. An analysis of this information will allow you to select a route to your destination that will minimize the vulnerability of the aircraft to Threat weapons and obstructions. Ideally, you would select a route that would mask the aircraft from Threat weapons; however, the terrain features that mask the aircraft may require the minimum enroute altitude to be so high that the aircraft can be detected by electronic devices. To insure that all factors are considered when selecting the tactical airway, the following guidelines are provided:

Correction for wind drift must be computed to insure accurate navigation.

a. A factor in route following is the availability of radio beacons and where they are positioned. In some situations, there may be only one beacon available. Because the reliable reception distance of the beacon signal is approximately 15 kilometers (km), it may be necessary to use

dead-reckoning (DR) navigation during some portion of the route (fig 23-2). Even when two or more radio beacons are available, they may be so far apart that a segment of the route must be conducted using dead-reckoning (fig 23-2). To avoid the danger of exceeding the limits of the safety zone, the dead-reckoning segment of the route should not exceed 15 km. Using this criteria, it would be possible to navigate 60 km using one radio beacon before receiving the signal from a second beacon along the course line (No. 1, fig 23-2). If the beacon is located at the beginning or end of the enroute course, the maximum safe distance you could navigate using dead-reckoning and radio navigation would be 30 km (No. 2, fig 23-2). Before final selection of the tactical airway is made, you must study the terrain within the enroute safety zone to determine the MEA. After determining the MEA for each leg of the route, you may find the MEA subjects the aircraft to detection by Threat weapons. To avoid this danger, you should select another route that would permit the aircraft to be flown at a lower MEA. After it has been determined that the selected route provides the best protection from Threat weapons and terrain obstacles, you should measure the azimuth and distance of each leg. Remember, the grid course of each leg must be converted to magnetic course. Also, when conducting dead-reckoning navigation, correction for wind drift and instrument error must be applied to insure accurate navigation.

Grid azimuth must be converted to magnetic azimuth.

b. After determining the magnetic course and distance of each leg, draw on the back of the Flight Log (DA Form 2283) in the miscellaneous data block a tactical

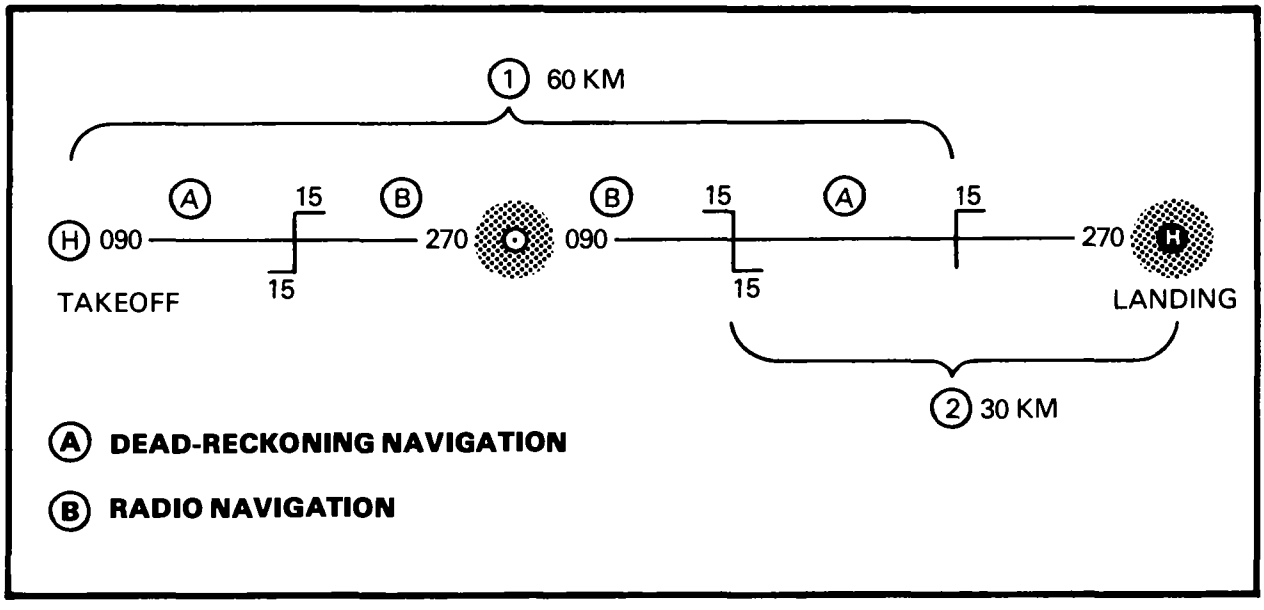


Figure 23-2. Enroute navigation.

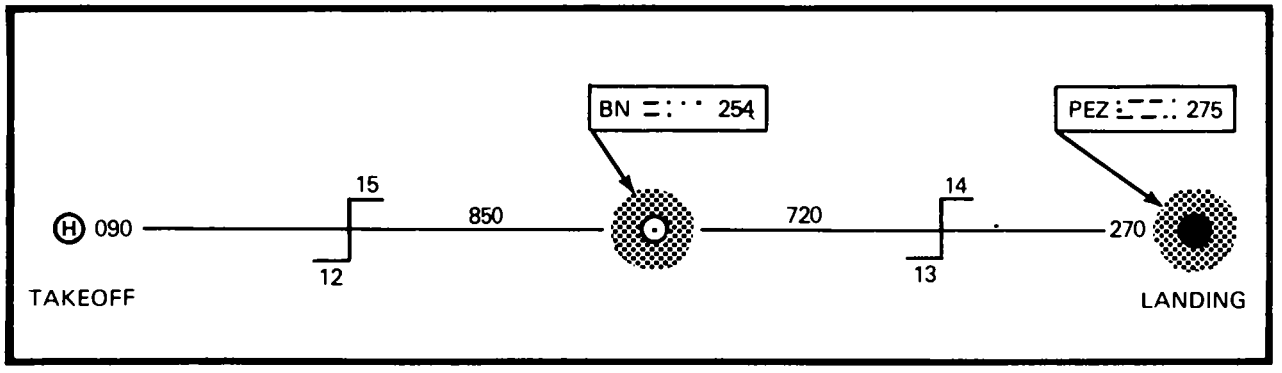


Figure 23-3. Tactical instrument map.

instrument map depicting the route that has been selected.

Note. The route should be oriented in relation to the actual route planned.

The exact scale of the map is not critical. The distance of each leg (measured in kilometers) and magnetic course should be recorded on the map (fig 23-3). If a portion of the leg is conducted using dead-reckoning navigation, mark the point where radio reception can be anticipated. Because the enroute altitude is normally below 1,000 feet AGL, surface winds should be used for computing enroute time and wind correction. This information should be recorded on your instrument flight log (fig 23-4). (If the diagram is too large for sufficient detail to be included, use a separate 5 x 8 sheet of paper.) If the leg is flown using both radio and dead-reckoning navigation, compute the time for each portion of the leg separately. After completing your preflight planning, you can add the minimum enroute altitude for each leg of the route.

ARMY AVIATION INSTRUMENT FLIGHT LOG

ATC CLEARS _____ TO _____

TEMP 15°C

WIND 300/10 TAS 88K

TAKE OFF	LANDING	MAG HDG / IAS	DISTANCE TOTAL / LEG / REMAINING	REQUIRED ETE / ATE	ETA / ATA	AVAILABLE ALTITUDE / GND SPD	REMARKS
PT OF DEP		90	12	+08		850	
						96	
START OF BN LEG	AN	90	15	+10		850	
	254					96	
END OF BN LEG		90	13	+08		720	
						96	
START OF PEZ LEG	PEZ	90	14	+09		720	
	275					96	

Figure 23-4. Flight log.

Due to the low altitude you will be flying when conducting tactical instrument flight, it is essential that you perform a thorough map analysis to determine the highest obstacle within the safety zone bordering the course line. Failure to recognize the highest obstruction could result in the aircraft being flown at an altitude below an obstruction within the enroute safety zone,

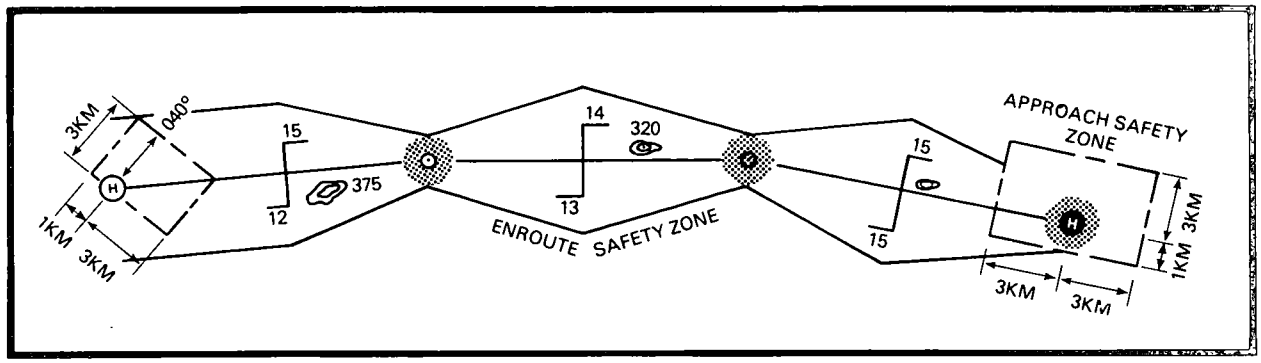


Figure 23-5. Factors for determining MEA.

thus creating an unsafe condition of flight. In addition to the information contained on the map, you should consider any PIREPs of manmade features that have been constructed since the map was printed. Although obstruction clearance is of primary concern, consideration must also be given to avoiding detection by enemy electronic devices. You may find that if the aircraft is flown at the MEA, it would be detected by Threat weapons. When this condition exists, you should select another route where the MEA is lower. Always remember to fly at the lowest minimum enroute altitude possible. This means that each leg of the route may be flown at a different altitude. The following procedures describe the method for determining the MEA.

a. The MEA for each leg of a tactical instrument airway may be different. To determine the MEA for each leg of the route, you must consider one or more of the following safety zones: The takeoff, the enroute, or the approach. For example, the MEA for the first leg is determined by the highest obstructions within the takeoff safety zone and the enroute safety zone (fig 23-5). If the route has three or more legs, the MEA for the leg(s) other than the takeoff and landing leg, is determined by the highest obstacle within the enroute safety zone (fig 23-5). The MEA for the final leg is determined by the highest obstacle within the enroute safety zone and the approach safety zone. For the purpose of the discussion within this paragraph, it will be assumed that the highest obstacle within the takeoff and approach safety zone is lower than the enroute safety zone.

b. The method of navigation that is used to maneuver the aircraft along the tactical airway (radio navigation or dead-reckoning navigation) will determine the procedure for computing the width of the safety zone. The following criteria will be used for determining the safety zone for each type of navigation.

(1) *Radio navigation*—within 15 km of the radio beacon: The width of the safety zone should be 2 kilometers wide at the beacon (1 km each side of the beacon) and gradually broaden to a point equal to one-fifth the distance of the leg at the midpoint. If a fraction of a kilometer

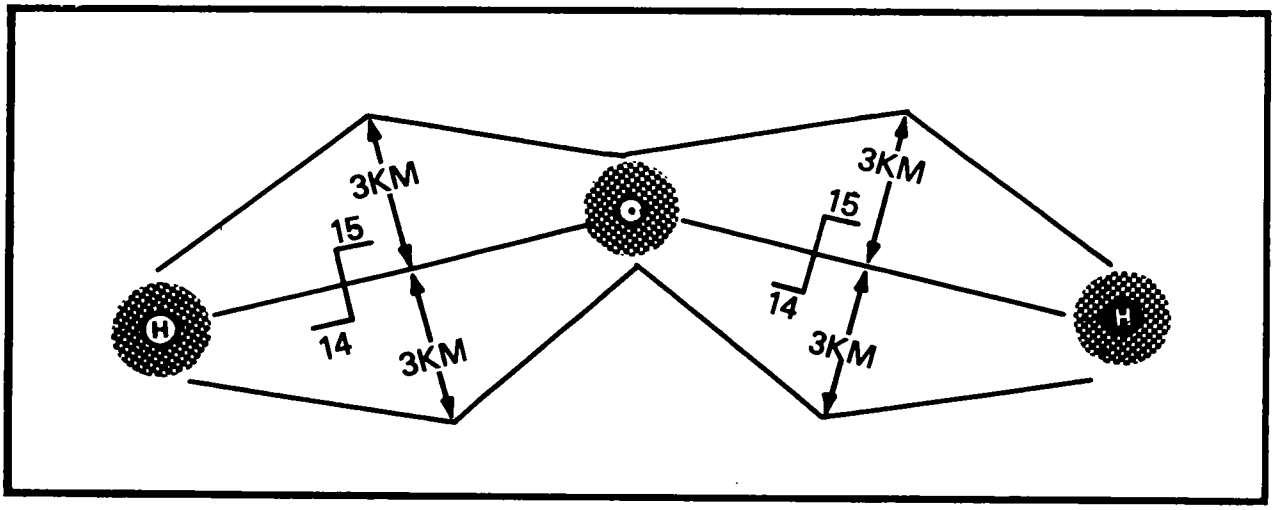


Figure 23-6. Safety zone for radio navigation.

results, round up to a whole kilometer (fig 23-6). The boundary line is drawn on each side of the course leg from a point 1 km abeam the beacon to a point 3 km from the centerline of the course at the midpoint (fig 23-6).

Example: The tactical mission requires that you perform an aviation support mission during IMC. The route consists of two legs fixed by three radio beacons. Radio navigation is possible for the entire route. To determine the safety zone for each leg, you must first measure the total distance of each leg. The widest part of the safety zone is one-fifth the total distance or 6 km for each leg in the example.

(2) *Dead-reckoning navigation*—dead-reckoning should not exceed 15 km. The width of the safety zone shall be one-fifth the length of the course leg. If a fraction of a kilometer results, round up to whole kilometer (fig 23-7).

Example: The tactical situation requires that you perform an aviation support mission during IMC. The route requires that the initial portion of the flight be flown using dead-reckoning navigation. To determine the safety zone for this portion of the leg, you must first measure the total distance of the leg (30 km). The width of the safety zone is one-fifth the total distance of the leg or 6 km. Draw the boundary line 3 km on each side of the centerline for that portion of the leg flown using dead-reckoning navigation.

(3) *Radio and dead-reckoning navigation.* When the course leg is flown using both radio navigation and dead-reckoning, the length of the leg should not exceed a total of 30 km. To determine the width of the safety zone for the portion flown using radio navigation, a line is drawn from the boundary of dead-reckoning safety zone to boundary of the radio navigation safety zone at the radio beacon.

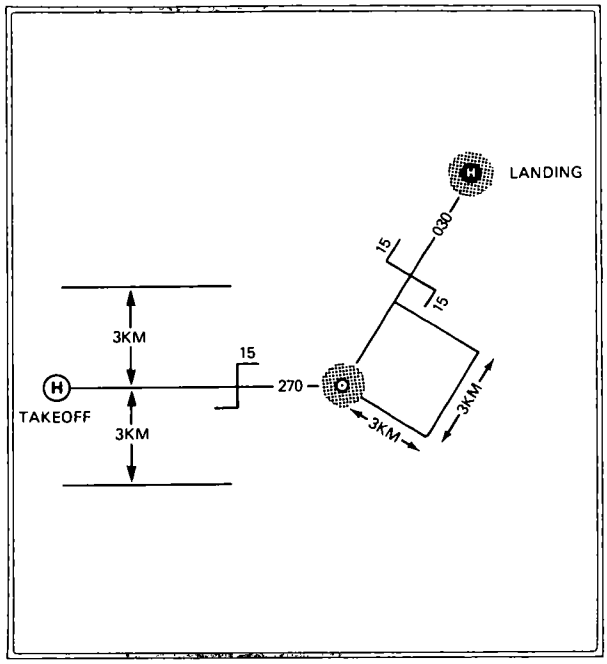


Figure 23-7. Safety zone for dead-reckoning navigation and turning.

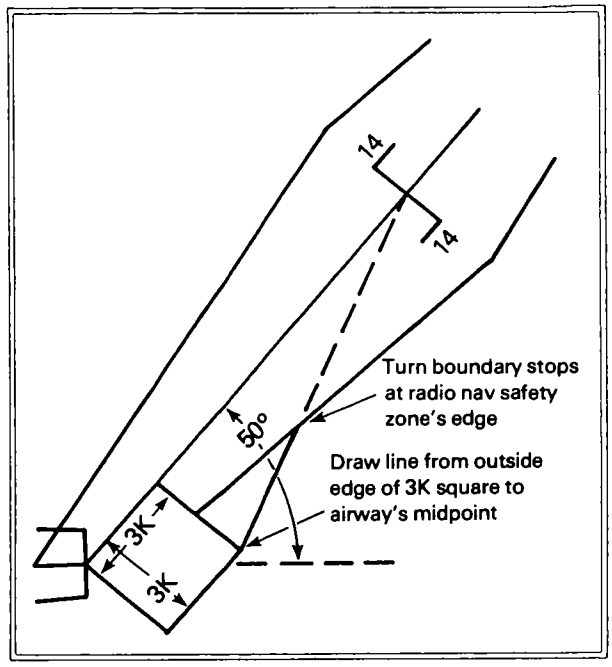


Figure 23-7a. Safety zones for dead-reckoning navigation segment, radio navigation segment and enroute turn (greater than 45°)

Example: The tactical situation requires that you perform an aviation support mission during IMC. The route requires that each leg of the route be formed using both dead-reckoning and radio navigation. To determine the safety zone for the portion of each leg flown using dead-reckoning navigation, follow the procedures described in the dead-reckoning navigation example. To determine the limits of the safety zone for the portion of each leg flown using radio navigation, draw a line from the safety zone boundary limits where dead-reckoning navigation ends or begins to the safety boundary limits at the beacon (fig 23-8).

c. When the enroute course changes more than 45°, the aircraft can be flown outside the enroute safety zone during the turn. To insure obstacle clearance, a turn safety zone should be constructed on the side of the enroute course where the turning radius of the aircraft would extend outside the enroute safety zone. The turning safety zone should be 3 kilometers wide and extend 3 kilometers beyond the radio beacon or fix where the turn will be performed (fig 23-7). Taper safety zone as shown in figure 23-7a.

CAUTION: The indicated airspeed (IAS) for enroute travel should not exceed 90 knots (kt). Airspeeds greater than 90 knots may cause the aircraft to be flown outside the safety zones. Also, difficulty will be experienced when decelerating the aircraft to 60 knots during the approach.

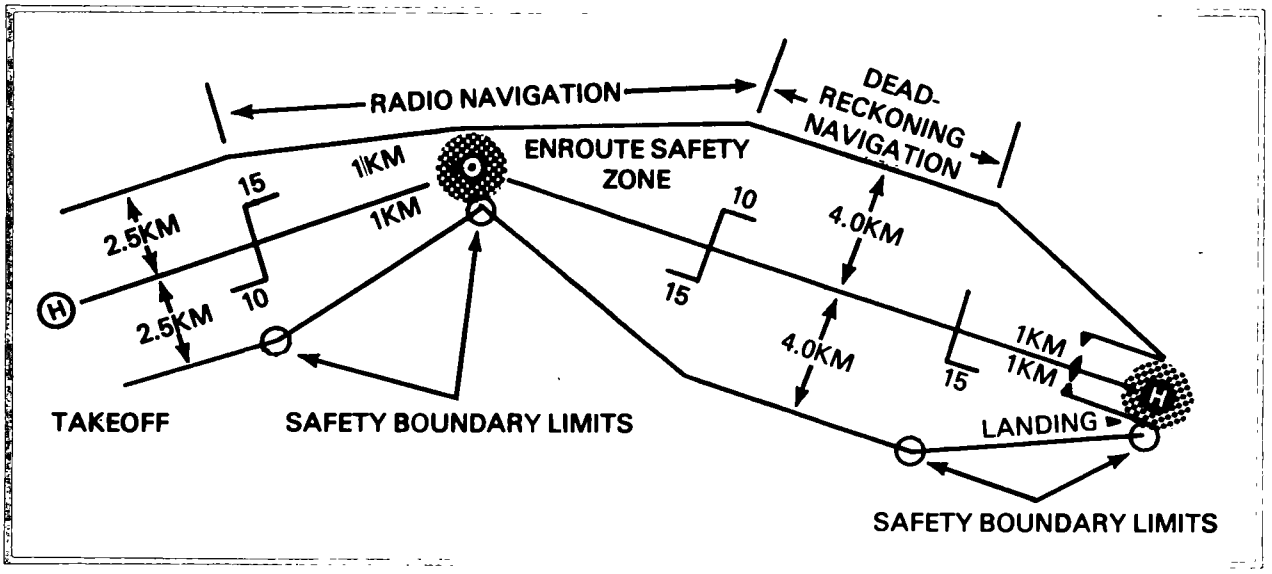


Figure 23-8. Safety zone for dead-reckoning and radio navigation.

d. After determining the boundary of the safety zone for each leg of the route, you should construct the boundary for the takeoff and landing safety zone. The procedure for determining the takeoff and landing safety zone will be discussed in the following paragraphs. For the purpose of this discussion, the assumption will be made that the highest obstruction is located within the enroute safety zones. Study the area within the safety zone and identify the altitude of the highest terrain or obstruction. Once the highest altitude is located, add 400 feet. This altitude is the recommended MEA for tactical instrument flight.

Note. **The recommended safe minimum clearance altitude of 400 feet above the highest obstacle (AHO) incorporates a safety margin for the variables of altimeter error, pilot error, obstacle elevations, and height of vegetation not depicted on tactical maps. At 200 feet AHO, the lowest beacon reliable reception altitude, the safety margin for the variables is not adequate. Altimeter error, variation in obstacle elevation, and heights of vegetation may be greater than 100 feet. Flights at 300 feet AHO would be satisfactory without considering potential pilot error. To allow for pilot error, an additional 100 feet is added as a safety margin, making the recommended safe minimum clearance altitude 400 feet AHO. Depending on the type of terrain—flat desert, broken woodlands, or mountainous—the safe minimum clearance altitude for flight planning purposes can and should be adjusted commensurate with the threat**

and terrain. For example, the safety margin can be reduced over flat desert terrain since vegetation or manmade obstacles are usually absent; in mountainous terrain, the margin may need to be increased to provide for downdrafts and unexpectedly high terrain obstacles.

MEA = HIGHEST OBSTRUCTION IN SAFETY ZONE + 400 FEET

Example (fig 23-9): The tactical situation requires that you perform an aviation support mission during tactical instrument flight conditions. After constructing the safety zones for each leg of the route and the takeoff and landing safety zone, you identify the altitude of the highest obstruction on the first leg to be 450 feet, 320 feet for the second leg, and 500 feet for the third leg. The MEA for the first leg is determined to be 850 feet AGL, 720 feet AGL for the second leg, and 900 feet AGL for the third leg (fig 23-9).

Note. **Obstructions shown on the map identify the height of the obstruction above the ground. To determine the altitude of the obstruction, you must add the height of obstruction to the terrain elevation.**

23-14. TAKEOFF PLANNING

Planning for the takeoff should include all the factors for a normal VMC takeoff; e.g., wind direction and velocity, longest axis of the area, barriers on the takeoff path, and power requirements. In addition,

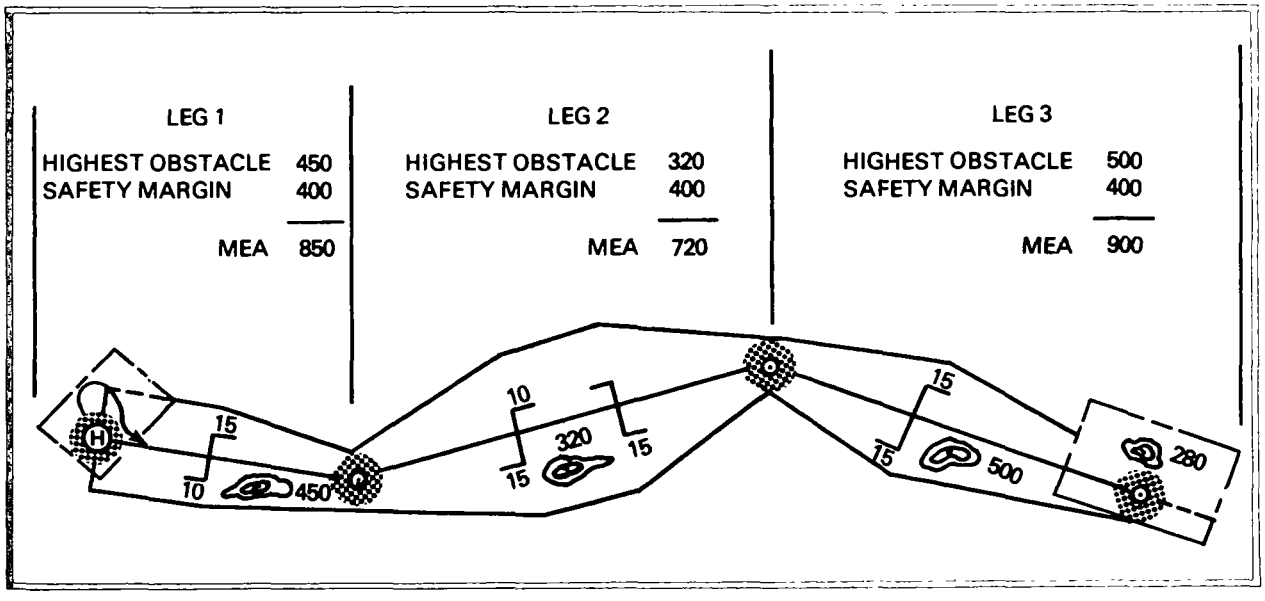


Figure 23-9. The highest obstruction for each leg of the route determines the MEA for that leg.

since the takeoff may be in actual weather conditions, you must evaluate the terrain within the takeoff safety zone to insure the climb performance of the aircraft will allow you to climb to an altitude above the obstacle before reaching it. When possible, the takeoff direction should be planned to be on or near the heading of the first leg of the course. Because this cannot always be accomplished, procedures have been established which will allow you to maneuver the aircraft safely to the desired course. If there is a navigational aid at the takeoff point, standard tracking procedures can be used to establish the aircraft on the desired course.

a. When the takeoff heading is within 90° of the enroute course, make a direct turn to the enroute course heading after reaching an altitude 100 feet above the highest obstruction within the takeoff safety zone (fig 23-11).

b. When the takeoff heading is more than 90° from the enroute course heading, a teardrop turn is used to reverse direction and establish the course heading. After reaching an altitude 100 feet AHO within the takeoff safety zone, execute a 210-degree turn (fig 23-11a). The turn should be made in the direction of the lowest terrain obstacles. Where terrain obstacles are not a consideration, the turn should be made into the wind. After completing the turn, fly the heading the same length of time as the takeoff heading was flown. After this period of time elapses, turn to the heading which will allow you to make good the desired course.

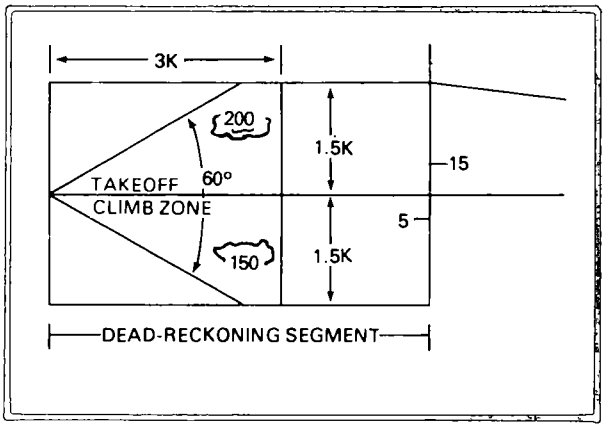


Figure 23-10a. Takeoff climb zone, dead-reckoning segment. Takeoff heading alined with enroute course.

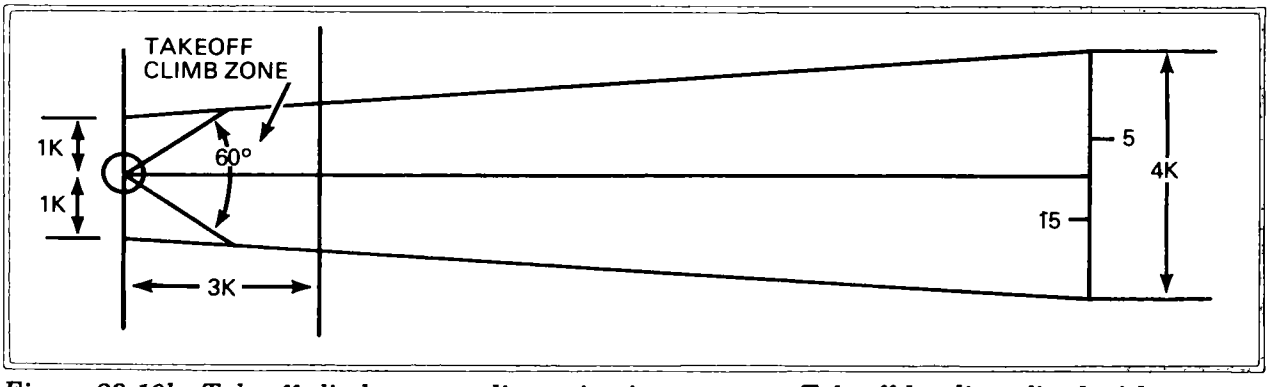


Figure 23-10b. Takeoff climb zone, radio navigation segment. Takeoff heading alined with enroute course.

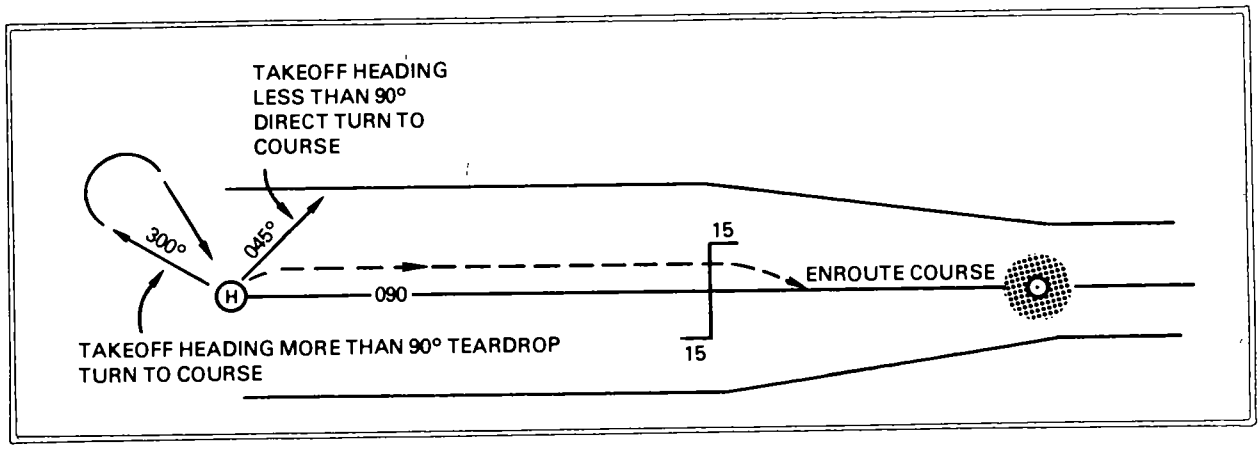
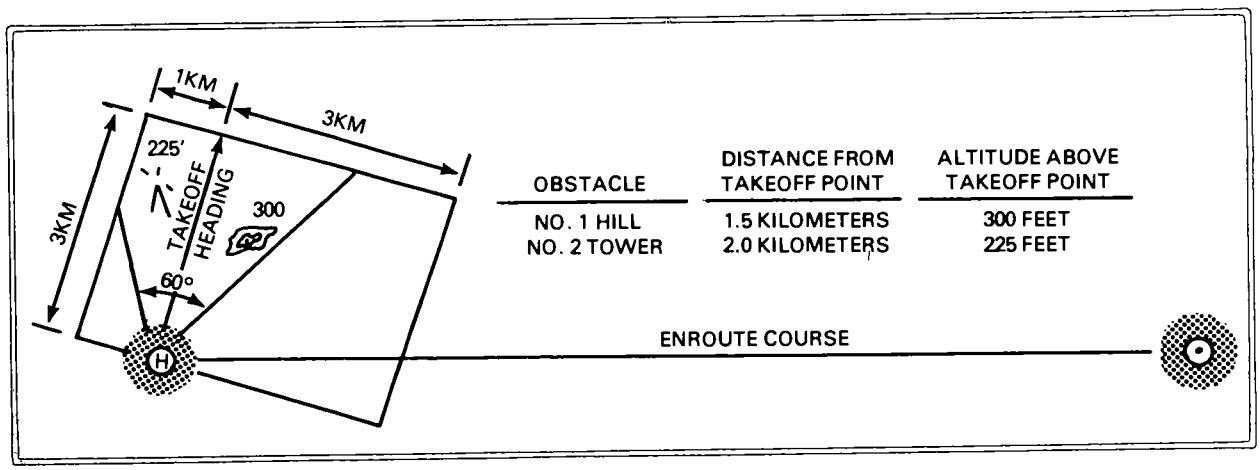


Figure 23-11. Takeoff to intercept enroute course.

c. When executing any of the tactical instrument takeoff maneuvers, a maximum takeoff power setting should be used while accelerating to 60 knots. After reaching 100 feet AHO in the takeoff safety zone, an acceleration to 90 knots and a power reduction to 500 feet per minute (fpm) should be initiated. The initial high rate of climb and slower airspeed is necessary to gain altitude in a short distance.

d. If the takeoff heading is alined with the enroute course, a takeoff safety zone is not required; but a takeoff climb zone is plotted to insure obstacle clearance during initial climb to MEA. (See figure 23-10a and b.) In all other cases, you must construct both a takeoff safety zone and a climb zone to insure obstacle clearance (fig 23-12).

(1) To develop a takeoff safety zone, construct a box 4 x 3 kilometers with the line dividing the maneuvering and nonmaneuvering sides of the safety zone alined on the takeoff heading (fig 23-12 and 23-14). The origin of this line is at the



OBSTACLE	DISTANCE FROM TAKEOFF POINT	ALTITUDE ABOVE TAKEOFF POINT
NO. 1 HILL	1.5 KILOMETERS	300 FEET
NO. 2 TOWER	2.0 KILOMETERS	225 FEET

Figure 23-12. Takeoff climb zone.

takeoff point. The 3 x 3 kilometer box of the takeoff safety zone will always be located on the turning side. Draw a climb safety zone within the takeoff safety zone.

(2) The climb safety zone should be drawn 30° each side of the takeoff heading and should extend from the takeoff point until intercepting the boundary of the takeoff zone. Identify the height of the highest manmade or natural obstacles within the climb zone and the distance from the takeoff point. Using the takeoff obstruction chart (fig 23-13), you can determine the rate of climb required to clear any obstacle within the climb safety zone.

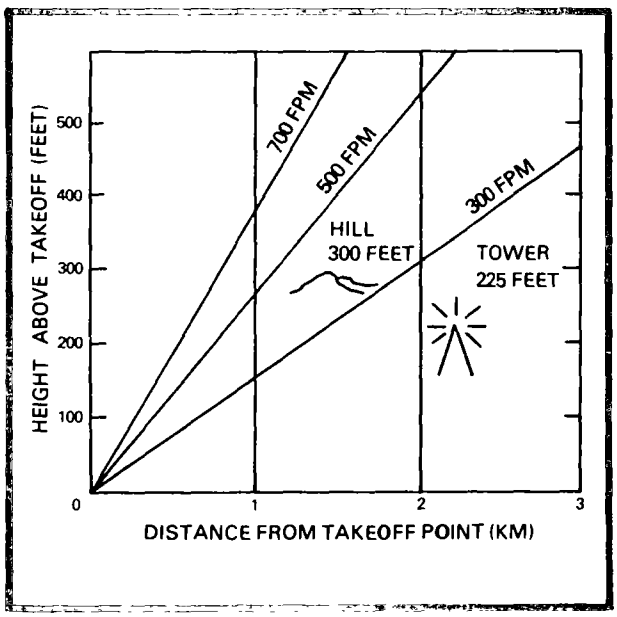


Figure 23-13. Takeoff obstruction chart for an airspeed of 60 knots (112.5 km).

Example: It is determined that there are two obstacles within the climb zone. By plotting these two obstacles on the takeoff obstruction chart, it can be determined that a climb rate of 500 fpm is required to clear these obstacles by a safe margin.

e. Determine the highest terrain feature or obstacle within the takeoff safety zone. This altitude plus 100 feet is the altitude you must climb to before turning to intercept the enroute course.

(1) Locate the altitude of the highest terrain feature or obstacle within the takeoff safety zone and the safety zone for the first enroute leg. Add 400 feet to the highest obstruction within these two safety zones. This is the MEA for the first leg of the route, and the aircraft must be flown to this altitude while turning to intercept the enroute heading.

(2) The MEA for succeeding legs of the route may be different. To minimize detection of the aircraft, you should fly each leg at its MEA rather than the entire route at the altitude of the highest MEA. If the succeeding leg of the course is higher, plan your climb so as to cross the radio beacon at the highest MEA. If the altitude is lower, descend to the MEA after passing the radio beacon.

(3) Refer to figure 23-14a. When flying outbound from beacon A to B, the 500-foot hill boosts MEA to 900 feet mean sea level (MSL).

MEA can be reduced to 550 feet by plotting an offset course (030° OB from beacon A) to avoid hill. Initially, on a 030-degree course, the plotted relative bearing to B is 20°, (050 minus 030). As

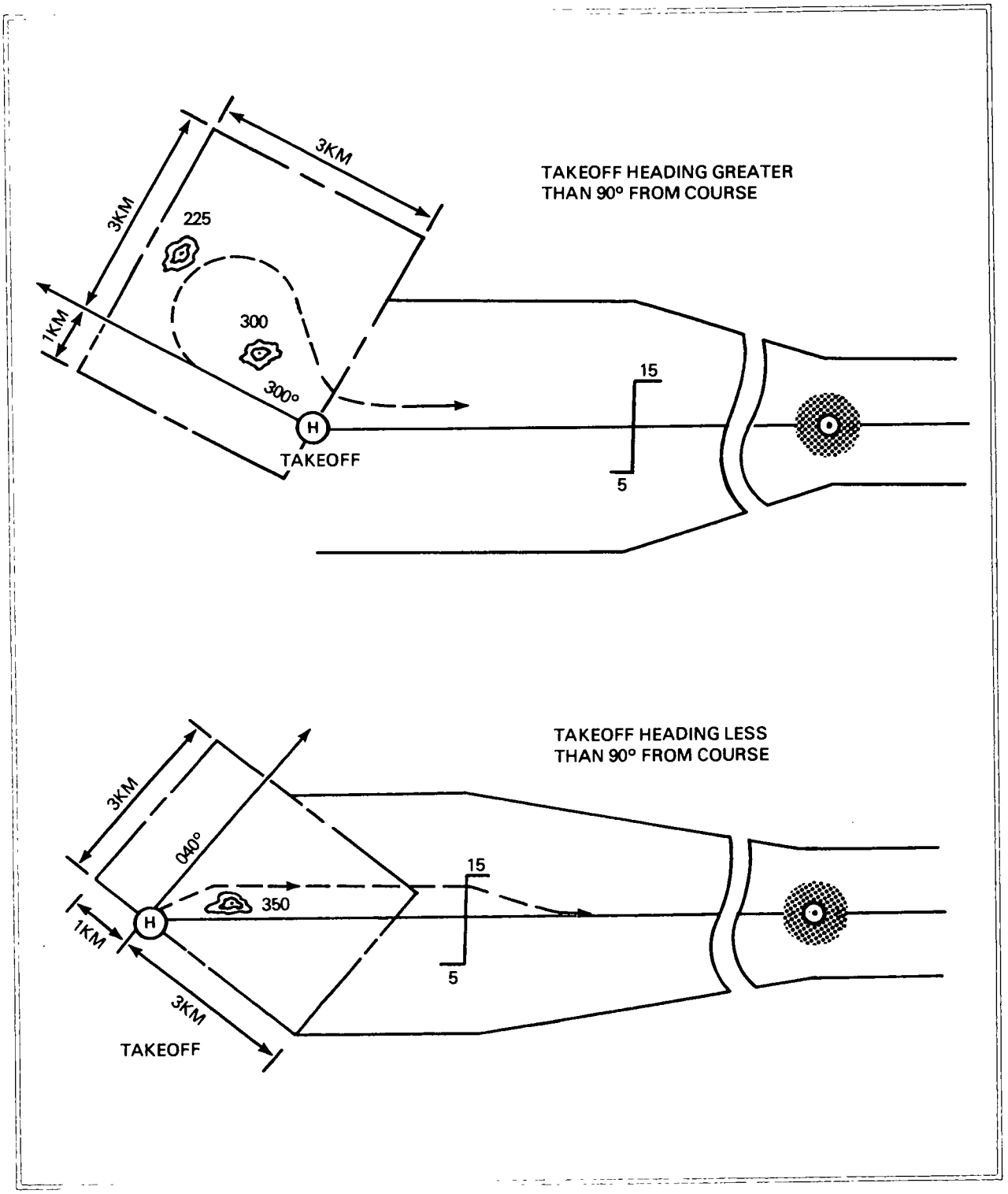


Figure 23-14. Takeoff safety zone.

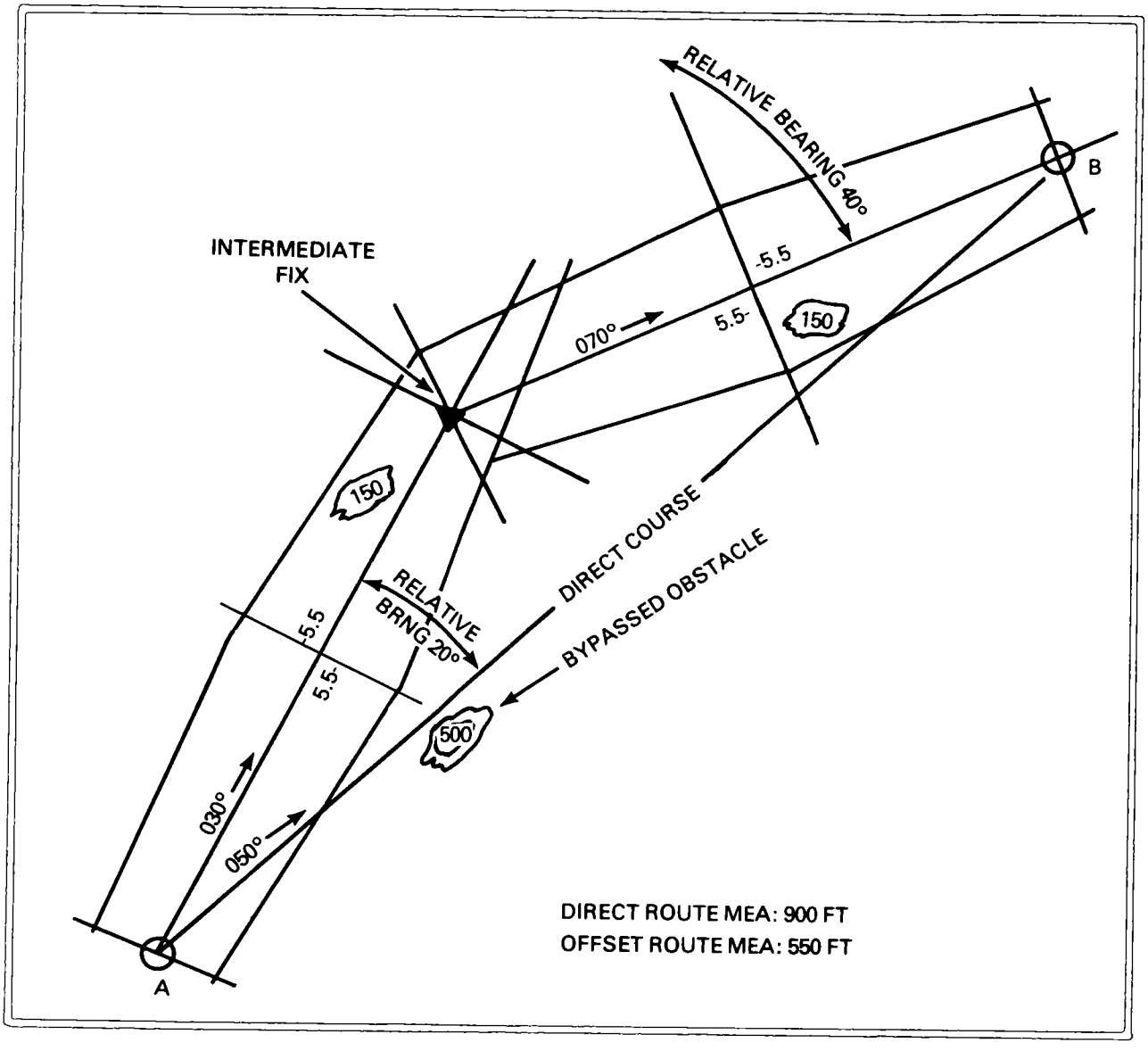


Figure 23-14a. Offsetting course to bypass direct route obstacle.

flight progresses outbound, the relative bearing gradually increases until it finally doubles (40° RB) at intermediate fix.

Since the aviator has maintained 030° outbound from A, he cross-tunes back and forth to B in order to maintain the outbound track and to note RB increase. When angle doubles, (40°), he is at intermediate fix, and turns right to B on a 070-degree course.

Distance from A to fix is same as from fix to B. Time en route from either beacon to fix will be the same in calm wind.

By using relative bearing change and doubling the relative bearing angle, the aviator reduced MEA while bypassing the 500-foot hill. Doubling-the-angle technique works only inbound to a beacon. A left crosswind increases relative bearing by the same amount of crab angle. A right crosswind reduces relative bearing by amount of crab angle.

23-15. APPROACH PROCEDURES

The tactical instrument approach incorporates the normal flight procedures used for the standard instrument approach; however, the minimum descent altitude (MDA) for the tactical approach is lower. There are two types of tactical approaches—*the terminal approach and the straight-in approach.* The flight maneuvers and procedures for constructing the approach safety zone for the tactical approach are as follows:

a. *Terminal Approach.* The radio beacon used for the terminal approach is located at the landing point. There is no final fix where the descent is initiated. The standard 1-minute racetrack pattern is used to maneuver the aircraft into position for the descent (fig 23-15). Because there is limited space within the approach safety zone, the aircraft should be flown at 60 knots airspeed. Reduction in airspeed should be made upon arrival at the beacon. Also, the aircraft must be flown to the minimum maneuver altitude within the approach safety zone (400 feet above the highest obstruction within the approach safety zone) prior to initiating the approach. If the MEA is higher than the minimum maneuver altitude, descend to the lower altitude in the pattern. Upon intercepting the approach course, begin descent so as to arrive at the MDA prior to reaching the beacon. Maintain track and MDA until station passage.

The approach safety zone for the terminal approach provides a safe maneuvering area for entering the racetrack pattern, holding and missed approach. Following are the procedures for constructing the approach safety zone.

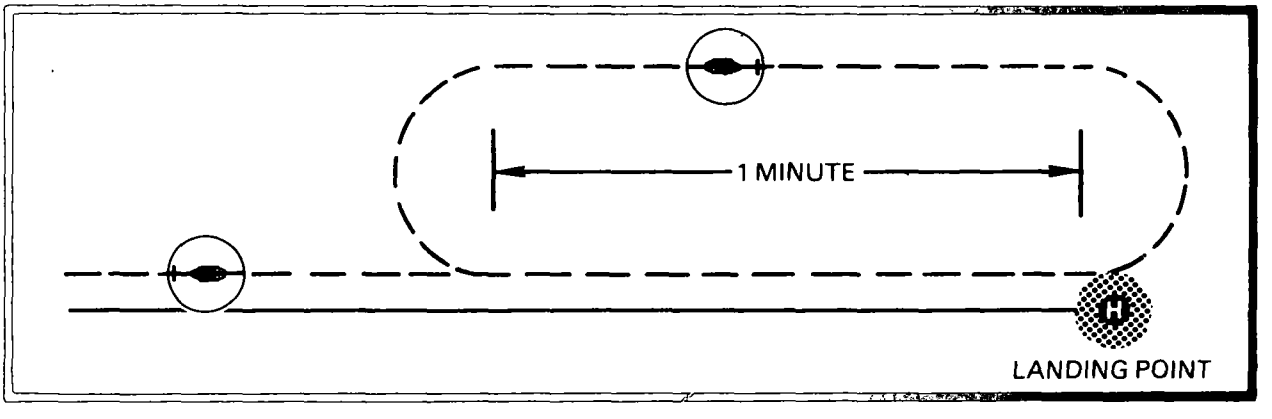


Figure 23-15. Terminal approach pattern.

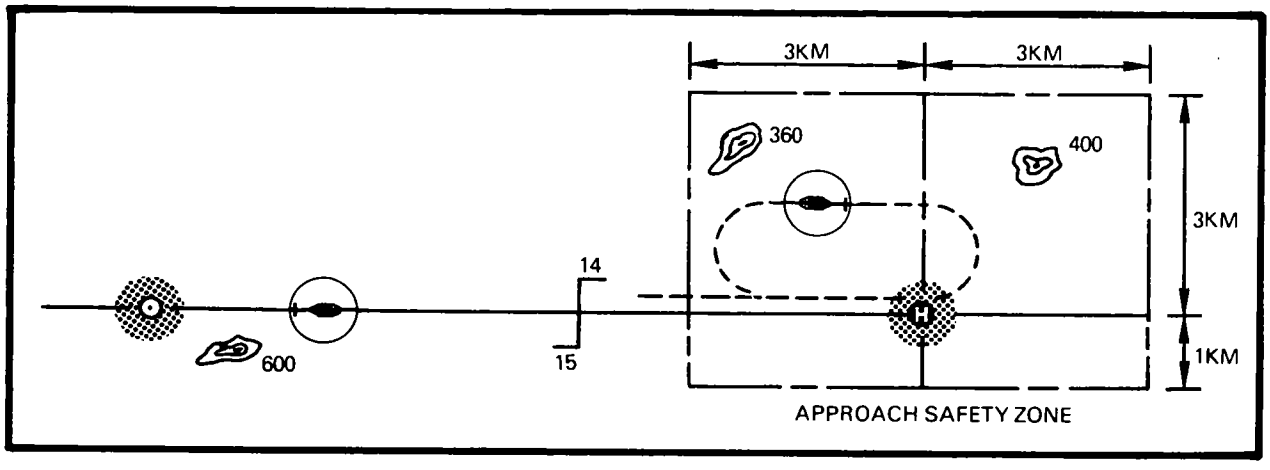


Figure 23-15a. Approach safety zone (terminal approach).

(1) The lateral boundaries of the approach safety zone are 3 kilometers on the maneuvering side and 1 kilometer on the nonmaneuvering side (fig 22-15a). The linear boundaries extend 3 kilometers on each side of the beacon. The maneuvering side should be located on the side where the terrain is the lowest. Where terrain is not a factor, it should be positioned on the downwind side.

(2) Study the area within the approach safety zone and locate the highest obstruction. The MDA is derived by adding 200 feet to the altitude of the highest obstruction. As discussed previously, the MEA for the final leg of the course may be determined by the highest obstruction within the approach safety zone.

(3) A diagram of the approach should be drawn to provide a visualization of the maneuvers to be performed during the execution of the approach.

MDA = HIGHEST OBSTRUCTION WITHIN APPROACH SAFETY ZONE + 200 FEET

Example (fig 23-16):

Altitude of highest obstruction within the approach safety zone . . . 400 feet (MSL)

Minimum enroute altitude . . 1,000 feet (MSL)

Minimum maneuver altitude within approach safety zone . . . . . 800 feet (MSL)

Minimum descent altitude. . . . 600 feet (MSL)

Sequence I—Decrease airspeed to 60 knots upon crossing the radio beacon. After passing the beacon, turn to parallel the outbound heading and begin descent to the minimum maneuver altitude within the approach safety zone.

Sequence II—After 1-minute outbound, turn to the inbound course. If the descent to the minimum maneuver altitude for the approach safety zone (800) is completed prior to intercepting the final approach course, continue the approach inbound to the landing

point. If additional time is required for the descent, fly the pattern until reaching the minimum maneuver altitude. Upon intercepting the final course inbound, begin descent to MDA.

Sequence III—If at any time on the approach visual contact is made with the ground, transition to VMC flight. If visual contact is not possible, execute missed approach procedures upon station passage. Missed approach procedures are discussed in the paragraph entitled "Missed Approach Procedures."

b. *Straight-In Approach.* To perform a straight-in approach, you must be able to identify a point along the enroute course where the approach begins. This point may be identified by an intersection formed by the two magnetic bearings or by passing over an enroute nondirectional beacon (fig 23-17). Normally, there is sufficient distance between the final fix and the landing point to permit a standard rate of descent from the enroute altitude to MDA prior to reaching the landing point; however, when necessary, you may enter holding on the inbound course to the fix and descend to the minimum maneuver altitude within the approach safety zone. A reduction in

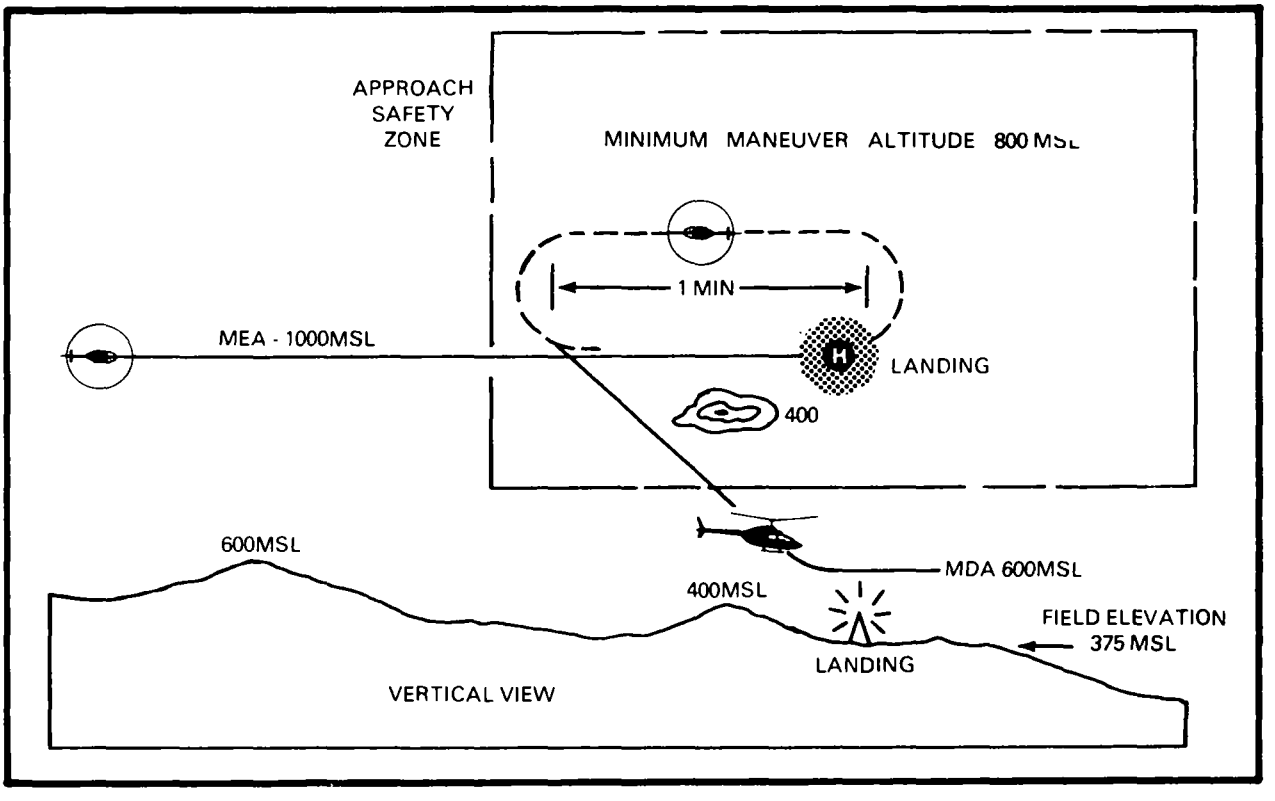


Figure 23-16. Terminal approach procedures.

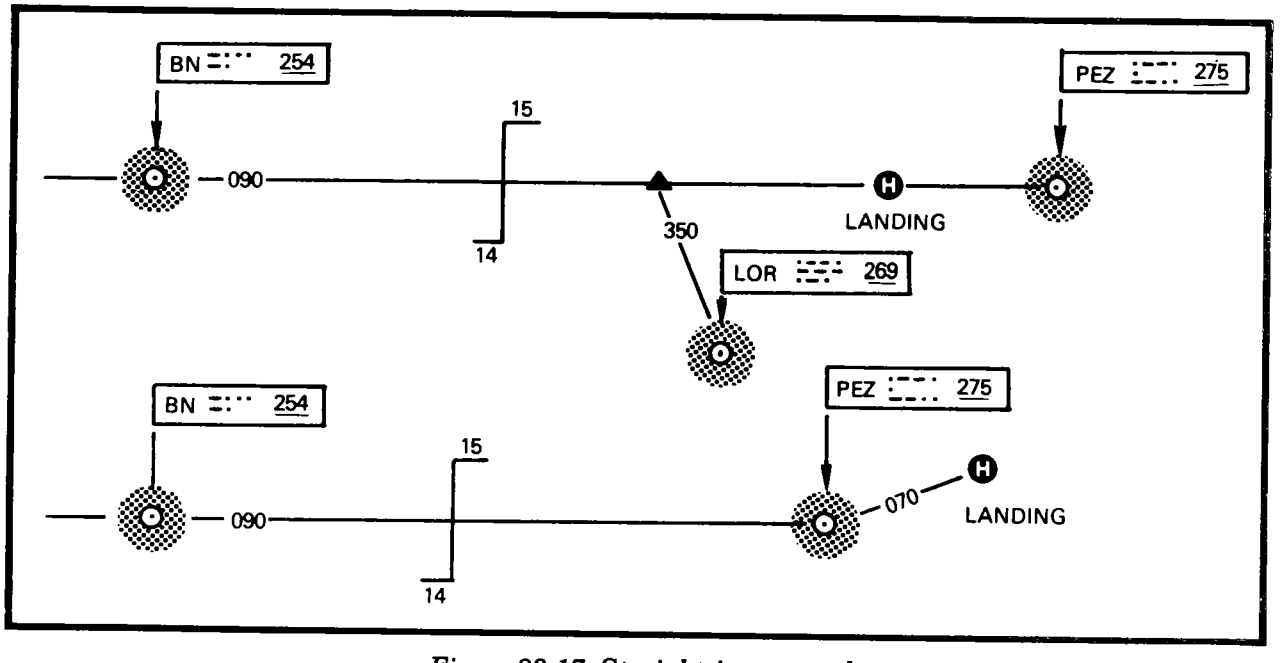


Figure 23-17. Straight-in approach.

airspeed to 60 knots should be made prior to arrival at the fix. Upon passing the fix, descend to MDA and track on the inbound course.

(1) When using a radio beacon or the intersection of magnetic bearings as the final fix, the following factors must be considered.

(a) Determine the location along the course where reliable intersection identification can be established. Terrain obstructions will limit the range and altitude at which a reliable signal can be received.

(b) The secondary radio beacon should be no more than 10 km from the intersection. This restriction is necessary to insure accurate intersection identification.

(c) Locate the intersection so the magnetic bearings forming the intersection are as close to 90° as possible.

(d) The landing point should be no less than 2 km and no more than 8 km from the final fix.

(2) The approach safety zone for the straight-in approach provides a safe maneuvering area for holding, the approach, and missed approach. The lateral boundaries are 3 kilometers on the maneuvering side and 1 kilometer on the nonmanuevering side (fig 23-18). The linear boundaries will vary depending on the distance the intersection is from the landing point. Regardless of what this distance may be, the safety zone will extend 3 km in front of the intersection to a point 3 km beyond the landing point. The guidelines for the construction of the approach safety zone are applicable both

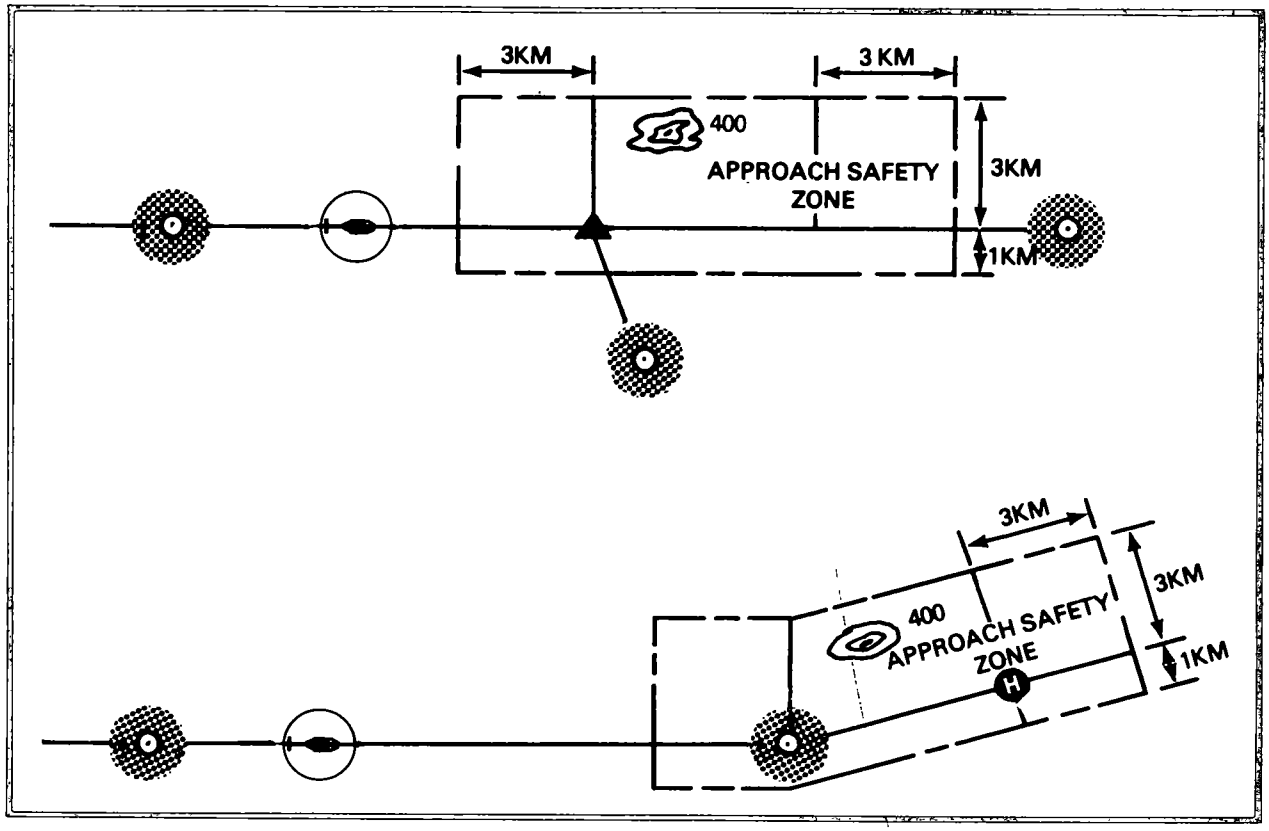


Figure 23-18. Approach safety zone (straight-in approach).

when the approach leg is alined with the enroute course and when offset from the enroute course.

(3) Study the area within the approach safety zone and locate the highest obstruction. Add 200 feet to the highest obstacle within the safety zone to determine the MDA. Also determine the minimum maneuver altitude within the approach safety zone by adding 400 feet to the highest obstruction. As previously discussed, this altitude may determine the MEA for the final leg of the route. If the minimum maneuver altitude for the approach safety zone is lower than the MEA, you can descend to this altitude while in the holding pattern.

(4) Measure the distance from the final approach fix (FAF) to the landing point and compute the time required to travel this distance at 60 knots groundspeed (GS). It may be necessary to enter holding if a high rate of descent is required to descend to MEA from a straight-in approach. Missed approach procedures will be executed when the time inbound from the fix elapses.

Groundspeed	Distance	Time
60	3 km	1:37

(5) A diagram of the approach should be drawn to provide a visualization of the maneuvers to be performed during the execution of the approach. Also, the

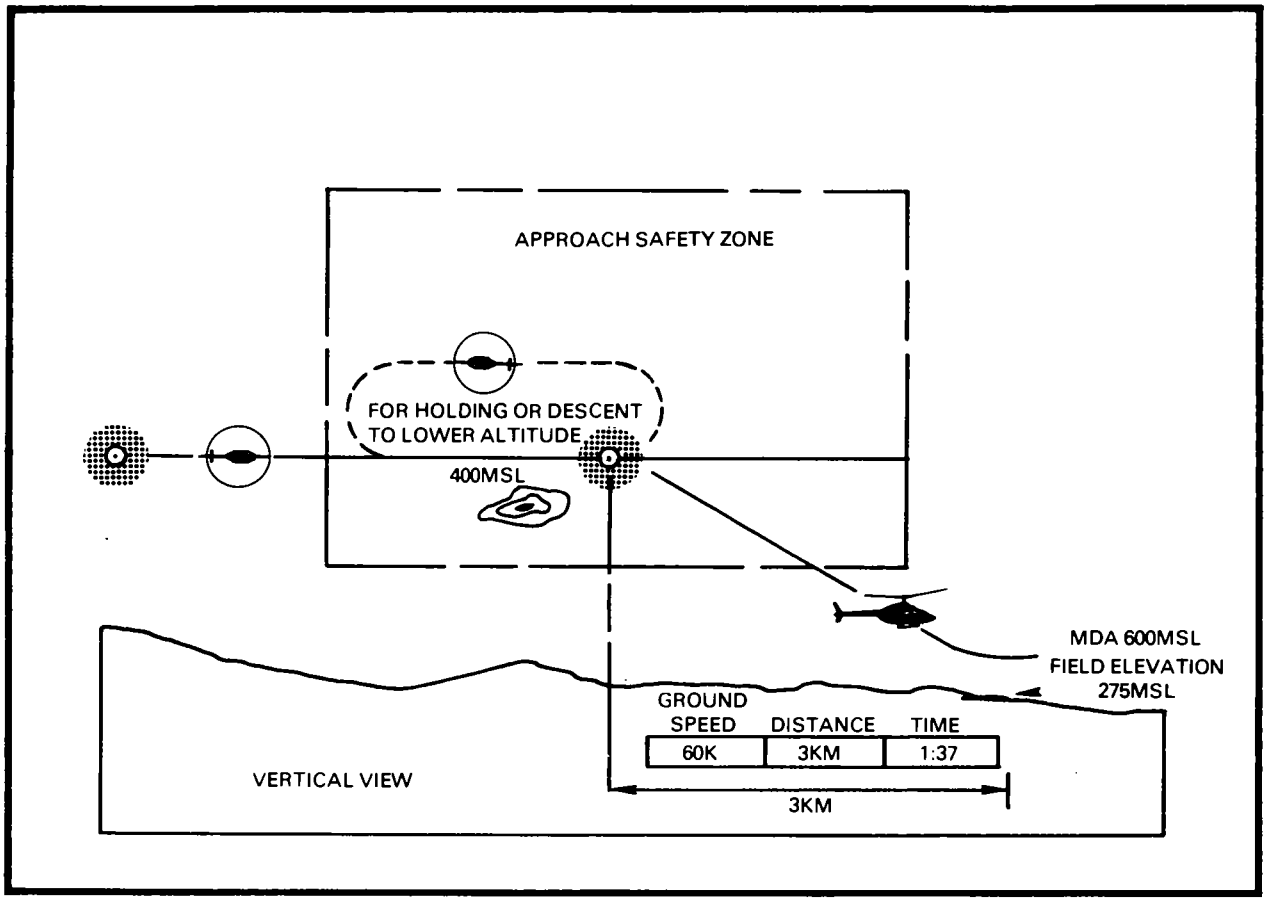


Figure 23-19. Straight-in approach procedure.

offset of the approach leg should not exceed 30° from the enroute course. When the final approach course is offset more than 45° from the enroute course, a turning safety zone should be constructed as discussed in paragraph 23-13c.

Example (fig 23-19):

Minimum enroute altitude 1,000
Minimum maneuver altitude within the approach safety zone 800
Minimum descent altitude 600
Time to landing point 1:37

Sequence I—Decrease airspeed to 60 knots upon crossing the final fix. After passing the fix, begin the descent and aline the aircraft on the inbound course. In this example, entry into the holding pattern is not necessary because the minimum rate of descent required to arrive at the MDA before reaching the landing point can be achieved.

Sequence II—Continue to track inbound and descend to MEA. If at any

time on the approach visual contact is made with the ground, transition to VMC flight. If visual contact is not possible, execute missed approach when the inbound time has elapsed.

[redacted]

a. Upon arrival at your destination, you may have to enter holding due to the tactical situation, or to let down to a lower altitude before executing the approach. The time flown in the holding pattern must be minimized to avoid detection and engagement by Threat weapons. Entry into holding is simplified because you will always hold on the enroute course. The decision whether to make left or right turns is optional; however, the direction of turn will be determined while on the ground during your preflight planning. Ideally, the holding pattern will be flown over the lowest terrain obstruction and on the upwind side of the course line.

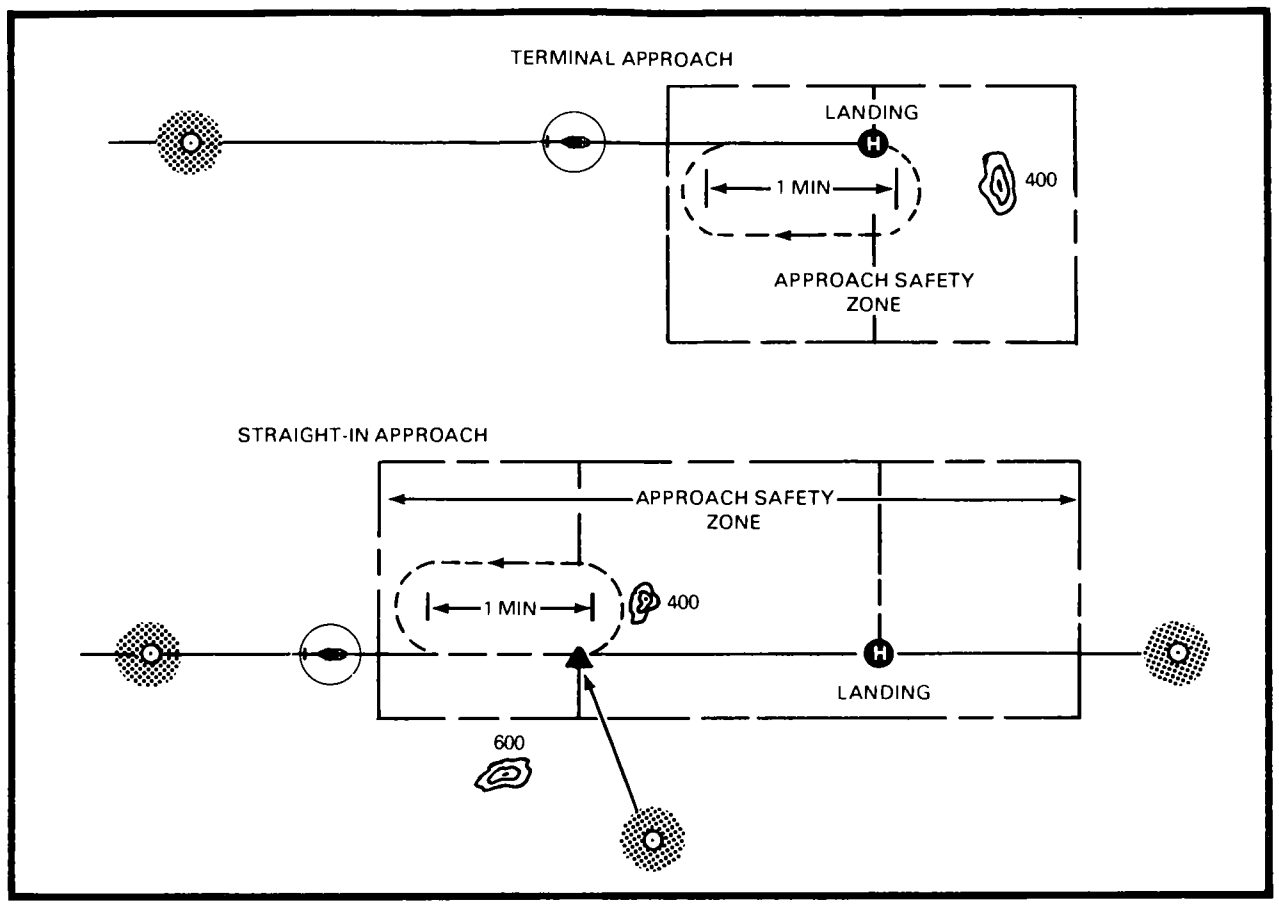


Figure 23-20. Holding pattern.

b. The holding pattern is limited to the standard 1-minute inbound leg. Airspeed while in the holding pattern is 60 knots. The approach safety zone includes a safe area for holding and is planned for in every approach. Holding should be conducted at the minimum maneuver altitude within the safety zone—400 feet AGL.

Example (fig 23-20):

Minimum enroute altitude . 1,000 MSL
Minimum maneuver altitude within the approach safety zone . . 800 MSL
Minimum descent altitude . . 600 MSL

Sequence I—Decrease airspeed to 60 knots upon crossing the fix. After passing the fix, turn to the outbound heading. Direction of turn should be toward the maneuvering side as determined in your preflight planning. Begin descent to minimum maneuver altitude (800 feet) after passing the fix.

Sequence II—Note time abeam the fix and fly outbound sufficient time to achieve a 1-minute inbound leg. Apply wind correction, as necessary, both outbound and inbound. Continue flight with holding pattern as required.

[redacted]

a. Weather conditions or the enemy situation may not allow you to land at your destination after initiating the approach. When either of these conditions exists, you must execute a missed approach. The

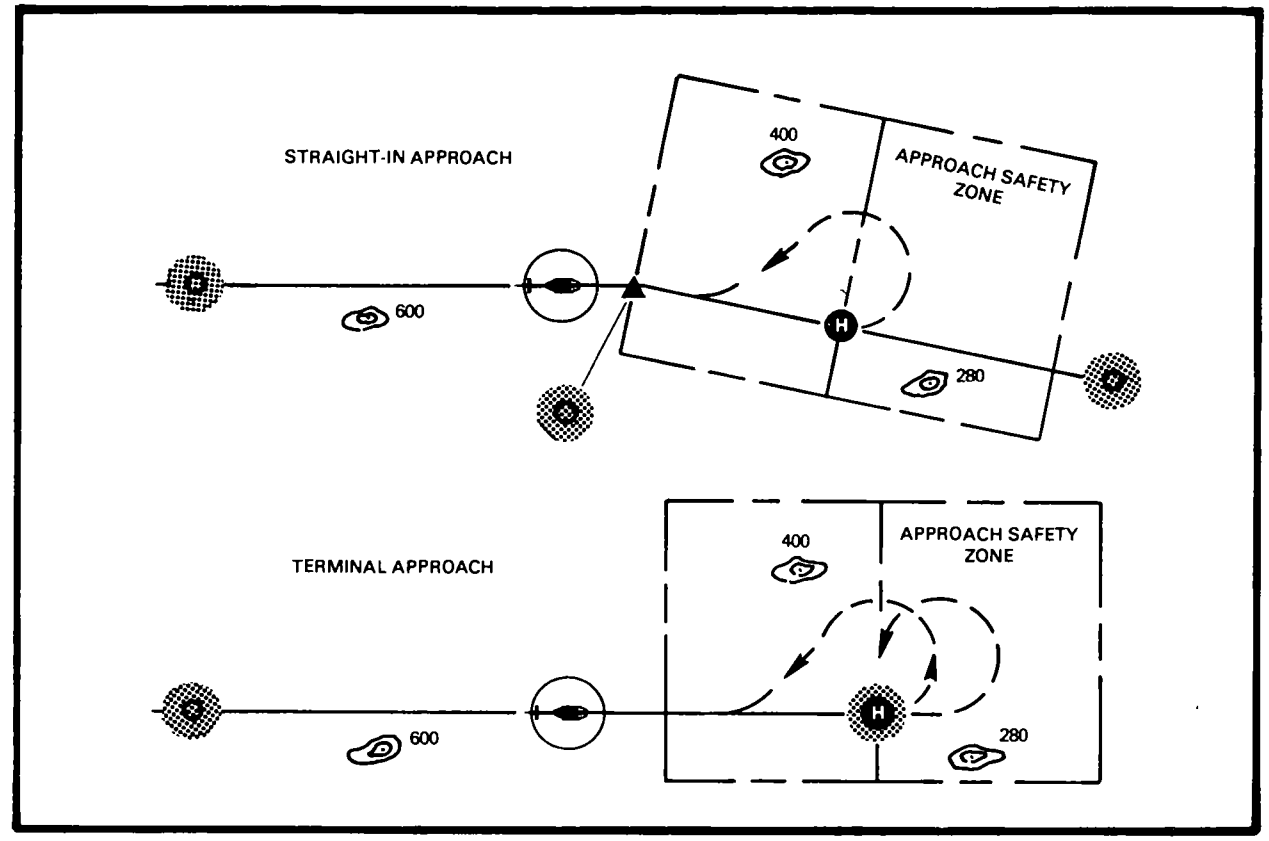


Figure 23-21. Missed approach procedure.

requirement to perform a missed approach must be anticipated for every tactical instrument flight. To insure obstruction clearance for the missed approach, a safe maneuver area is provided for in the approach safety zone. The maneuver for the missed approach is basically the same for both the terminal approach and the straight-in approach. It consists of a climbing left turn or right turn to intercept the reciprocal of the enroute course or return to the radio beacon. If the missed approach procedure is to intercept the reciprocal of the enroute course, use a 45-degree or more intercept heading.

b. During the preflight planning, you must determine the direction of turn. Normally, it is on the same side as the holding pattern is flown; however, you are not restricted to this procedure. The location of highest terrain obstructions and wind direction will dictate the direction of turn.

c. A diagram of the planned missed approach should be drawn to provide a visualization of the maneuver to be performed during the execution of the missed approach.

OPEN FOR FOLDOUT

Example (fig 23-21):

Minimum descent altitude . . 600 MSL
Minimum maneuvering
altitude . . . . . 800 MSL
Minimum enroute altitude . 1,000 MSL

Sequence I—Upon reaching the position where the missed approach must be executed, immediately initiate a climbing turn. Continue the turn until on a direct course to the radio beacon or on an intercept heading to reciprocal of the enroute course. The climb should be expedited to the minimum enroute altitude. An airspeed of 60 knots should be maintained during the climb.

Sequence II—Radio contact should be established with the FCC to advise of your intentions. If contact cannot be made, contact the ground unit to relay your request to the ATC personnel.

23-18. EMERGENCY PROCEDURES

The emergencies that you may experience while conducting tactical instrument flight will vary. The best procedures to cope with the emergency will be determined by the conditions that exist at the time of the emergency. Good judgment and positive action are essential to insure survival of the aircraft and aircrew. Although not complete, the following are emergency conditions that might be experienced. Also presented are recommended actions.

a. *Air Defense Emergency Procedures.* Even though the enemy cannot visually acquire and engage your aircraft when conducting instrument flight in the clouds, electronic devices have this capability. The route you fly should minimize vulnerability to Threat weapons. However, while en route, your AN/APR-39 radar detector may activate, indicating the aircraft is being tracked by enemy radar. Unless immediate action is taken to reduce altitude, you will soon be engaged. To descend below the MEA is dangerous; however, you must break electronic line-of-sight by descending. To minimize the danger involved, you should decelerate the aircraft to the minimum controllable forward airspeed. Simultaneously initiate a descent. At a specific altitude, you will lose radar line-of-sight. Descent below this altitude is not required unless you have flown into VFR conditions. If you are still in the clouds, you must decide whether to continue to your destination or reverse course. Primary factors that you must consider are:

(1) What are the weather conditions?

(2) What is your altitude above the highest obstruction?

(3) In which direction are the lowest obstructions located?

(4) Is the landing point or takeoff point closer?

(5) Are there suppressive countermeasures available to degrade the Threat weapons?

(6) Is there any battle damage to the aircraft? If so, what effect does it have on continued flight?

b. *Loss of Radio Navigational Aids.* While en route to the landing point, you may experience a loss of signal from the radio beacon. Each situation of this nature requires good judgment. General guidance that may be followed is:

(1) If the radio beacon fails when your position is within 15 kilometers of the beacon, reduce airspeed to 60 knots and continue on the route for 2 minutes. If the signal is not received within this period of time, reverse course and use dead-reckoning navigation, as required, to return to the takeoff point.

(2) If the radio beacon fails when you are beyond the effective range of the radio beacon, you will not know immediately that it has failed. If no audio signal is received upon reaching the time where the radio signal should be received, execute a course reversal.

(3) If the radio beacon fails during the approach, continue the approach to the MDA; but do not continue inbound after reaching the MDA unless visual contact is made with the ground.

(4) If the radio beacon fails while holding, do not initiate the approach; instead, turn to the reciprocal of the enroute heading and return to the takeoff point.

(5) If in close proximity to the landing point and ground personnel can identify your position by sound, use ground personnel to talk you down.

(6) If radio contact can be established with the pathfinder at the beacon, FM homing can be used as an emergency means of navigation.

c. *Aircraft Deficiency.* Any number of aircraft emergencies may occur during a tactical instrument flight. *These emergencies can be categorized as land immediately, land as soon as possible, land within a specified time.* The first two emergencies are simple go or no-go indications of flight. The third condition must be evaluated to determine if you should continue or abort the mission. Factors that must be evaluated to determine what emergency action should be taken are:

(1) Have you reached the point of no return where it would be closer to continue on to the intended point of landing?

(2) Can a safe landing be made at the landing point based on the emergency, the nature of the landing area, the load and the enemy situation?

(3) If the emergency requires you to perform a full stop landing from the approach, even if visual conditions cannot be established, slow the aircraft to minimum controllable airspeed and descend at a slow rate. If visual contact is not established at MEA, continue the descent until visual contact with the ground.

(4) Can a takeoff be made after landing at a field site? Due to the nature of the emergency, a safe takeoff from a field site may not be possible; however, return flight to the takeoff point can be accomplished.

(5) How critical is the mission? It may be more important to get the cargo to its destination and let the aircraft remain on the ground at the field site until further flight is possible.

Section IV. TRAINING

23-19. INTRODUCTION

a. Units qualifying aviators in tactical instrument flight are responsible for conducting a well-organized training program. The POI must instill confidence within the student that tactical instrument flight can be performed safely in a high threat environment and at low altitudes. The student undergoing this training should be qualified and proficient in instrument flight. Before conducting the flight portion of the training, the student should demonstrate a knowledge of the preflight training that is required for instrument flight. Teamwork between the pilot and copilot is essential. Whereas 50 feet to 100 feet above or below assigned altitude is not critical for normal instrument flight, it is very serious when conducting tactical instrument flight. The copilot should advise the pilot when the aircraft deviates from an assigned altitude or is being flown off-course. Maintaining precise positioning of the aircraft is esssential for tactical instrument flight.

b. To acquire the proficiency that is required to conduct tactical instrument flight, the training must be continuous. Command emphasis is essential to insure that the aviators assigned to the unit achieve and maintain the required proficiency to conduct tactical instrument flight in an actual combat environment. Where possible, the synthetic flight training simulators (SFTS), in conjunction with actual in-flight training, should be used to obtain and maintain the required degree of proficiency.

c. Tactical instrument training flights conducted during VMC require no unusual precautions; however, when conducted during actual instrument conditions, the commander must insure that:

(1) Actual tactical instrument training flights are conducted in a controlled training environment and only on predetermined routes with all obstacles clearly noted. These routes must be coordinated with local and government air traffic authorities (e.g., the coordination for major training exercises, or local coordination to establish semi-permanent training routes). Authorities must then determine the necessity of publishing the proposed air routes and/or the notification of civil airspace users as necessary.

(2) Actual tactical instrument training flights are conducted only when destination weather is expected to be at, or greater than, minimum descent altitude at time of arrival $\pm$ 1 hour.

(3) Missed approach procedures are coordinated with local airspace authorities to allow immediate transition to necessary alternate airfields. Alternate airfields should be selected in accordance with criteria established for normal IFR flight in AR 95-1.

[redacted]

A recommended program of instruction for qualifying aviators for tactical instrument flight is provided.

FLIGHT TRAINING FOR TACTICAL INSTRUMENT FLIGHT

TASK	CONDITION	TYPE INSTRUCTION	REFERENCES	TRAINING/EVALUATION STANDARDS
Identify the prerequisite for conducting tactical instrument flight.	Classroom	Conference	AR 95-1 FM 1-5 FM 1-60 TERPs	The student must demonstrate a knowledge of instrument flight procedures, regulations, and flight techniques.
Identify the threat and how it affects tactical instrument flight.	Classroom	Conference	FM 1-5 FM 1-60 FM 90-1 FM1-88	The student must demonstrate a knowledge of Threat weapons and their capabilities. The student must also know the planning requirements that will avoid or minimize detection of the aircraft by Threat weapon systems.
Identify the condition during which tactical instrument flight will be conducted.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of the meteorological conditions that require the use of tactical instrument flight.
Identify the principles of employment for instrument flight in the combat zone.	Classroom	Conference	FM 1-5 FM 1-60 FM 90-1	The student must demonstrate a knowledge of the different flight altitudes that will be flown within the different areas of the combat zone, the NAVAIDs available, classes of approaches, and the control procedures to be followed.
Identify the factors that must be considered when planning a tactical instrument flight.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of the factors that are required for initial planning of a tactical instrument flight. This includes the mission requirements; e.g., what, where, when, and who, the enemy situation, the location of AD weapons, the weather condition, communications, NAVAIDs and special equipment.

FLIGHT TRAINING FOR TACTICAL INSTRUMENT FLIGHT

TASK	CONDITION	TYPE INSTRUCTION	REFERENCES	TRAINING/EVALUATION STANDARDS
Describe the two types of nevigetion used for tactical nevigation.	Clessroom	Conference	FM 1-5	The student must demonstrete e knowledge of the capabilities end limitetions for both dead-reckoning and redio navigetion es reletes to tacticel instrument flight planning.
Describe the procedure for determining the enroute course.	Clessroom	Conference	FM 1-5	The student must demonstrete a knowledge of the cepabillties of the redio beacon, conversion of grid azimuth to megnetic ezimuth, and measurement of distence in kllometers.
Describe the procedures for construction of the enroute sefety zone.	Classroom	Conference	FM 1-5	The student must demonstrete e knowledge of how to construct an enroute safety zone for dead-reckoning nevigetion, radio nevigetion, or a combination of deed-reckoning and redio nevigetion.
Describe the procedures for determining the MEA.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of how to anelyze the erea within the enroute safety zone to determine the highest obstruction. After identifying the highest obstacle, the student must determine the MEA for each leg of the route.
Describe the procedure for intercepting the enroute course after takeoff.	Classroom	Conference	FM 1-5	The student must demonstrete e knowledge of how to intercept the enroute course when the tekeoff heading is less then or greater than 90° from the enroute course.

FLIGHT TRAINING FOR TACTICAL INSTRUMENT FLIGHT

TASK	CONDITION	TYPE INSTRUCTION	REFERENCES	TRAINING/EVALUATION STANDARDS
Describe the procedure for determining the takeoff climb zone.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of how to construct the takeoff climb zone, analyze the area within the zone for the highest obstruction, and determine when the turn to intercept the enroute course can be made.
Describe the procedures for determining the takeoff safety zone.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of the dimensions and orientations of the takeoff safety zone, how to analyze the area within the takeoff safety zone to determine the highest obstruction, and how to determine the MEA for the first leg of the route.
Describe the procedures for determining required rate of climb on takeoff.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of how to construct a takeoff obstruction chart and how to determine the required climb rate to clear obstacles within the takeoff climb zone.
Describe the procedures for performing a terminal approach.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of entry into the approach pattern, descent to the minimum maneuver altitude, the descent to MDA, and when to execute missed approach.
Describe the procedures for performing a straight-in approach.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of how to fix the final fix inbound; descend in the pattern, when necessary; descend to MDA; and when to execute a missed approach.

FLIGHT TRAINING FOR TACTICAL INSTRUMENT FLIGHT				
TASK	CONDITION	TYPE INSTRUCTION	REFERENCES	TRAINING/EVALUATION STANDARDS
Describe the procedures for determining the epproach sefety zone.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of the dimensions end the orientation of the approech sefety zone, how to enelyze the area within the epproech safety zone to determine the highest obstruction, and how to determine the MEA for final leg of the route.
Describe the procedures for determining the MDA for the epproech.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of how to determine the highest obstruction within the approech safety zone. Using this information, determine the MDA.
Describe the holding procedure.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of how to enter the holding pattern, the time of the inbound leg, direction of turn; how to determine the minimum maneuver eltitude for holding, and size of the meneuver area.
Describe the missed approech procedure.	Classroom	Conference	FM 1-5	The student must demonstrate a knowledge of when to execute the missed approach, the direction of turn, method of course interception, climb requirements, and size of the meneuver area.
Identify the categorles of emergency procedures end describe the recommended ections.	Clessroom	Conference	FM 1-5	The student must demonstrate a knowledge of emergency conditions that may result from acquisition of the eircreft by Threet weepons, loss of radio nevlgational eids, or aircreft deficiencies.

FLIGHT TRAINING FOR TACTICAL INSTRUMENT FLIGHT				
TASK	CONDITION	TYPE INSTRUCTION	REFERENCES	TRAINING/EVALUATION STANDARDS
Perform tecticel instrument tekeoff.	A tacticel instrument tekeoff will be performed. Tekeoff heeding will be less then or greeter then 90° from the enroute course.	Precticel Exercise	FM 1-5	The student must demonstrete the proper procedure for en instrument takeoff, required rete of climb, course interception, end climb to MEA.
Perform enroute tecticel instrument nevigetion.	Aircreft or SFTS will be flown over tecticel instrument route et MEA.	Precticel Exercise	FM 1-5	The student must demonstrete the proper procedures for deed-reckoning end redio nevigetion, meintein requlred eltitude, identify intersectlon or beecon pessege, end ettein eccurete estimetes of enroute time (± 1 minute).
Perform tecticel instrument epproech (terminel).	A tecticel instrument epproech will be performed.	Precticel Exercise	FM 1-5	The student must demonstrete the proper procedure for entry into the epproech pettern, descent to minimum meneuver eltitude within the epproech sefety zone, descent to minimum descent eltitude, trecking, trensition to VFR flight, end execution of missed epproech.
Perform tecticel instrument epproech (straight-In).	A tecticel instrument epproech will be performed.	Prectical Exercise	FM 1-5	The student must demonstrete the proper procedure for identifylng the finel fix, descent to MDA, trecking, trensition to VFR flight, execution of mlssed epproech, and when necessery, entry Into holding to descend to the minlmum meneuver eltitude prlor to initieting epproach.

FLIGHT TRAINING FOR TACTICAL INSTRUMENT FLIGHT				
TASK	CONDITION	TYPE INSTRUCTION	REFERENCES	TRAINING/EVALUATION STANDARDS
Perform holding at the radio beacon or intersection.	Tactical holding will be performed.	Practical Exercise	FM 1-5	The student must demonstrate the proper procedure for entry into the holding pattern, wind correction, and descent to minimum maneuver altitude.
Perform missed approach procedure.	Missed approach procedure will be performed following tactical approach.	Practical Exercise	FM 1-5	The student must demonstrate the proper procedure for entry into the missed approach, direction of turn, climb to MEA, and interception of the enroute course.
Perform simulated emergency procedure.	Simulated emergency conditions will be performed.	Practical Exercise	FM 1-5	The student must demonstrate a knowledge of the proper emergency procedures to be performed when confronted with an air defense emergency, loss of radio navigational aids, or aircraft deficiency.

APPENDIX A
REFERENCES

Department of the Army Pamphlets of the 310-series should be consulted frequently for latest changes or revisions of the references given in this appendix and for new publications relating to the material covered in this publication.

ARMY REGULATIONS (AR)

95-series	(Aviation)
310-series	(Military Publications)
310-25	Dictionary of United States Army Terms
310-50	Authorized Abbreviations and Brevity Codes

DEPARTMENT OF THE ARMY PAMPHLETS (DA PAM)

310-series	(Military Publications Indexes)

FIELD MANUALS (FM)

1-30	Meteorology for Army Aviators
1-60	Airspace Management and Army Air Traffic in a Combat Zone
1-88	Aviator's Recognition Manual
90-1	Employment of Army Aviation Units in a High Threat Environment

TECHNICAL MANUALS (TM)

*TM 95-226	United States Standard for Terminal Instrument Procedures (TERPS)

*To order copies, write:

S&I Directorate
USAATCA
ATTN-CCQ-AS-AI
Cameron Station
Alexandria, VA 22134

MISCELLANEOUS PUBLICATIONS (MISC PUB)

AFM 51-40	Air Navigation, Department of the Air Force and the Navy, 1 July 1973
DOD FLIP	DOD Flight Information Publications (FLIP)
FAA 7110.65A	Air Traffic Control

APPENDIX B

AIR TRAFFIC CONTROL (ATC) SHORTHAND SYMBOLS

B-1. GENERAL

The number of flight clearances which must be delivered by ATC does not permit excessive repetitions of a clearance. Also the speaking rate is too rapid for longhand copying of the clearance. Occasionally ATC will issue a clearance which differs from the original flight plan. In such cases, the aviator must be particularly alert to receive and understand the clearance given. Clarification should be requested if any doubt exists. As an aid in copying ATC clearances, a series of symbols has been devised for use as clearance shorthand.

B-2. COMMON ATC SHORTHAND SYMBOLS

Words and Phrases	Symbol
Above (altitude in hundreds)	5O
Advice	ADV
After (passing)	∠
Airway designation	V-7
All turns left	↰
Alternate instructions	(---)
Altitude 6,000	60
And	&
Approach	AP
Approach control	APC
Army	R
At	@
ATC Clears	C
As a fix	FX
Before (passing)	>
Below (altitude in hundreds)	$\overline{5O}$
Climb (altitude in hundreds) immediately	↑5O
Contact approach	CT
Contact (station) approach control	CT OZR
Contact (station) center	(OZR

Words and Phrases	Symbol
Course	CR
Cleared to cross	X
Cruise	→
Delay indefinite	DLI
Depart	DP
Departure control	DC
Descend to (altitude in hundreds) immediately	↓30
Direct	DR
Directions (bound) Eastbound	EB
Westbound	WB
Northbound	NB
Southbound	SB
Inbound	IB
Outbound	OB
Each	EA
Enter (in) control area	
Estimated time of arrival	ETA
Expect approach clearance	EAC
Expect further clearance	EFC
Fan marker	FM
Final	F
For further clearance	FFC
For further headings	FFH
From	FR
Heading	HDG
Hold (direction)	H-E
If not possible	OR
Initial approach	I
Intersection	INT
Intercept airway, jet route, or course	⟹
Left turn after takeoff	LT
Cleared to land	L
Locator outer marker	LOM
Maintain	M
Middle compass locator	ML
Middle marker	MM
Nondirectional radio beacon approach	NDB
Nonstandard pattern (for time in minutes)	(2)
No delay expected	Λ
Outer marker	OM
Out of (leave) control area	
Over (station)	OZR
Outer compass locator	OL

Words and Phrases	Symbol
On course	OC
Procedure turn	PT
Radar vector	RV
(Numerical designation) radial	045R
Remain well to left side	LS
Remain well to right side	RS
Report crossing	RX
Report departing	RD
Report leaving	RL
Report over	RO
Report passing	RP
Report reaching	RR
Request further altitude changes en route	RFACE
Reverse course	RC
Right turn after takeoff	RT
Runway (numerical designation)	RY18
Standard range	SR
Standby	SBY
Straight in	SI
Take off (or takeoff) (direction)	T→N
Tower	T
Traffic is	TFC
Track	TR
Until	U
Until advised (by)	UA
Until further advised	UFA
VFR conditions-on-top	VFR
Via	VIA
While in control area	Δ

[redacted]

a. "Army 72888, cleared ILS approach to Cairns, to runway 36, maintain 300 to outer compass locator, over."

C ILS AP OZR RY 36 M 30 OL

b. "Army 72888, expect ILS approach to Cairns, landing runway 36, wind 360 degrees at one zero, weather 600 feet overcast, visibility 2 miles in light rain and fog, altimeter 29.38, over."

ILS OZR LDG RY 36, 360/10 WX 6 OVC 2R-F 29.38

c. "Army 72888, radar contact 2 miles SE Hartford intersection, fly heading 270 for radar vector to ILS final approach course at Cairns over."

R 2 SE HARTFORD Δ HDG 270 RV ILS OZR

APPENDIX C

INSTRUMENT FLIGHT RULES (IFR) FLIGHT PLANNING

C-1. GENERAL

a. Planning for an IFR flight can be a simple operation requiring 10 minutes or it can be a complex operation requiring many hours. The extent of planning necessary is dependent on the nature of the mission, the type and number of aircraft on the mission, the distance to be flown, selected route, weather conditions, and available navigational facilities. The checklist items presented in this appendix provide general guidance for the individual aviator; they are especially applicable to instrument flight planning within the United States. The aviator's proficiency and judgment will dictate necessary modifications to these procedures and techniques.

b. An aviator assigned a specific mission usually must plan the flight for arrival at a fixed destination at a definite time. The type aircraft, the load, and the personnel on board are often predetermined by the mission. However, an aviator planning a proficiency flight can often choose the aircraft, the destination, route, time, and other factors which have a bearing on the flight. Where possible, the aviator attempts to control the variable factors affecting his mission to produce optimum flight conditions.

C-2. IFR FLIGHT PLANNING CHECKLIST

a. *Weather Briefing Sources.* A weather briefing can be obtained from the following persons or agencies:

(1) A military or civilian forecaster—in person.

(2) A forecaster—by local telephone.

(3) A recorded forecast—by local telephone.

(4) Flight Service Stations—in person.

(5) Flight Service Stations—by local or exchange telephone.

(6) Military or Weather Bureau forecasters—by long-distance collect telephone.

Note. Check current operational publications for procedures and listings.

b. *Weather Data Briefing.* The weather briefing should include—

(1) A forecast for destination and alternate airfields at estimated time of arrival to include—

(a) Ceiling and visibility. Check for compliance with regulations. The destination forecast will determine the requirement for selecting an alternate. If the minimum conditions specified by AR 95-1 will exist at the destination, an alternate airport is not required.

(b) Weather phenomena producing low ceilings and visibility.

(c) Hazards to flight, including thunderstorms, icing, gusty winds, and high density altitude.

(d) Height of cloud tops.

(2) An enroute forecast to destination and alternate airfields to include—

(a) Hazards to flight.

(b) Freezing level.

(c) Height of cloud tops and bases.

(d) Flight level winds and temperatures.

(3) An overall weather picture. The aviator, with the aid of a forecaster if possible, should obtain a clear mental picture of the overall weather situation including location of highs, lows, and frontal systems. The rate and direction of their movement, and the weather conditions associated with them, should be clearly understood by the aviator.

c. *Route Selection.* Select the best route based on—

(1) Weather conditions.

(2) Preferred routes. Check current operational publications for listings. Deviate from preferred routes when safety or the mission requires it.

(3) Direct routing. File for direct flight only if the mission requires it or if considerable savings of fuel or time can be realized. If the flight penetrates uncontrolled airspace, air traffic control (ATC) will not provide traffic separation.

d. *Route Survey.* Conduct a route survey to the destination and alternate airfields, using navigational charts to determine—

(1) Primary radio aids for enroute navigation. List frequencies, station identifiers, courses, and radials on the flight log.

(2) Supplementary radio aids to be used for position fixing and secondary navigation.

(3) Availability of ATC and weather radar en route.

(4) Distance between reporting points and total flight distance. Total distance is computed from takeoff to the destination radio facility.

(5) Minimum enroute IFR altitude (MEA), minimum reception altitude (MRA), and minimum crossing altitude (MCA).

Note. Check NOTAM and chart revision notices for latest changes in the status of navigational aids (NAVAID). Check listing of VHF omnidirectional range (VOR) shutdown information for alternate routing where appropriate.

e. *Altitude Selection.* Select the best altitude for the flight based on—

(1) *Weather conditions.* Avoid altitudes where icing and turbulence will be hazardous.

(2) *Direction.* In uncontrolled airspace, direction of flight based on hemispherical rule (below 29,000 feet).

(a) Odd altitudes are requested on magnetic courses from 0° to 179°.

(b) Even altitudes are requested on magnetic courses from 180° to 359°.

(3) *MEA, MRA, MCA.*

(a) Select altitudes that comply with published minimum altitudes applicable to the flight.

(b) On direct flights, determine minimum altitude based on charted obstacles and the requirements of the regulations.

(c) Do not plan a flight at the MEA if the flight level temperature will be significantly below standard. Lowering of pressure levels in air significantly colder than standard will result in the true altitude being significantly lower than the indicated altitude. Request an altitude assignment above the MEA under these cold air temperature conditions.

(4) *Aircraft performance and equipment.* In selecting a flight altitude, consider—

(a) Optimum operating conditions for the aircraft.

(b) Availability of oxygen.

(c) Radio equipment limitations (range, altitude, etc.).

(5) *Air traffic control.*

(a) Avoid relatively low altitudes which may conflict with approach control service in complex terminal areas.

(b) Do not request unnecessary altitude changes.

f. *Departure.*

(1) Plan the departure to comply with standard instrument departures (SID) at airports for which they have been established since ATC normally will employ SID if available. Be familiar with all SIDs since the controller may not authorize the particular one requested.

(2) Check for availability of departure control (conventional or radar). Note appropriate frequencies.

(3) Study the local area chart if one is published, or study the departure area on the enroute chart. Become familiar with the

radio facilities and intersections within the departure area.

g. *True Airspeed (TAS).*

(1) Compute and file the TAS accurately. Recompute the TAS later in flight to verify preflight calculation. If the actual TAS varies more than 10 knots from the filed TAS, notify ATC of the difference.

(2) Base true airspeed computation on the known indicated airspeed (IAS) for normal cruise and the forecast flight level temperature, or consult the aircraft operator's manual for true airspeeds based on gross weight, altitude, temperature, and desired cruise conditions (e.g., maximum range, maximum endurance, and short range).

> *Note.* **True airspeeds of a given aircraft can vary considerably depending on weight, altitude, and desired cruise condition. Don't guess—consult the aircraft operator's manual.**

h. *Groundspeed (GS).* Compute GS for each leg of the flight by combining the forecast winds with planned courses and the TAS (chap 14).

i. *Estimated Time En route (ETE).*

(1) Based on groundspeed and distance, compute the ETE for each leg of the flight between reporting points.

(a) On the initial leg, allow sufficient additional time for the planned departure and climb to flight altitude.

(b) If enroute climbs are made at reduced airspeed, allow additional time for *significant* changes on the leg.

(2) Compute the total ETE for the flight. This will be the estimated time required to reach the destination radio facility. Subsequent time required for transition, holding, and approach at the destination is not included in the ETE on an IFR flight.

(3) Compute the ETE to the alternate airfield from the destination or other critical positions along the flightpath.

j. *Fuel.*

(1) Compute the "fuel-on-board" flight plan entry by subtracting the warmup and takeoff fuel allowance (see the aircraft operator's manual) from the total fuel on board and dividing this quantity by the cruise consumption rate. The cruise consumption rate is determined by the cruise conditions and aircraft gross weight, as explained in the aircraft operator's manual.

(2) Compute total fuel required for the flight based on the appropriate consumption rate specified in the operator's manual, and include allowance for—

(a) Warmup and takeoff.

(b) Initial climb (consult aircraft operator's manual for extended climbs).

(c) Enroute cruise to destination and alternate. Allow time in addition to ETE for *known* enroute delays required

by the mission. Enroute ATC delays usually *cannot* be anticipated.

(d) Fuel reserves required for IFR flight (AR 95-1).

(3) Compute surplus fuel by subtracting total fuel required from total fuel capacity.

> *Note.* **Surplus fuel is important since enroute traffic delays, holding at the destination, and the instrument approach are not provided for in the fuel requirements specified in (2)(a) through (d) above. Research fuel is for UNFORESEEN circumstances. Do not plan to use reserves for routine delays.**

k. *Terminal Area.*

(1) If an area chart is published for the destination, study it carefully to become familiar with—

(a) Radio facilities and intersections.

(b) Published transitions and STARs.

(2) Study all published destination approaches which the aircraft is equipped to make. Become familiar with—

(a) Transitions.

(b) Final approach courses.

(c) Procedure turns.

(d) Approach minimums (decision height, or minimum descent altitude, ceiling, and visibility).

(e) Restriction, warning, and caution notes.

l. *Aircraft Clearance Form (Flight Plan).* Army aviators will use the DD Form 175 (Military Flight Plan) for flights within conterminous United States, Hawaiian, Alaskan, and San Juan Domestic Control Areas and for flights from conterminous US to Canada. FAA Form 7233-1 or 7233.3 (Flight Plan) may be used in lieu of DD Form 175 when departing US installations not having a military base operation facility.

m. *Flight Log.* The use of the Army aviation instrument Flight Log (DA Form 2283) is recommended. This provides for a concise summary of data required to execute the flight, allows for in-flight revision of data, and provides an accurate record of the flight. The flight log normally is supplemented by reference to the appropriate radio navigation chart.

APPENDIX D

FREQUENCY MODULATED (FM) HOMING

D-1. AN/ARC-44 AURAL HOMING

a. *General.* The AN/ARC-44 FM radio provides an aural homing system capable of homing to any FM radio transmitter that transmits in a frequency range of 24.0 to 51.9 Megahertz (MHz). The operation of this system is based on the phase of the incoming signal as it reaches the antennas. If the signal reaches the left antenna first, the aviator will hear the letter D (···) in Morse code. If the signal reaches the right antenna first, the aviator will hear the letter U (··—) in Morse code. When the signal reaches both antennas simultaneously, a solid tone will be heard and the station will be directly in front of or behind the aircraft (fig D-1).

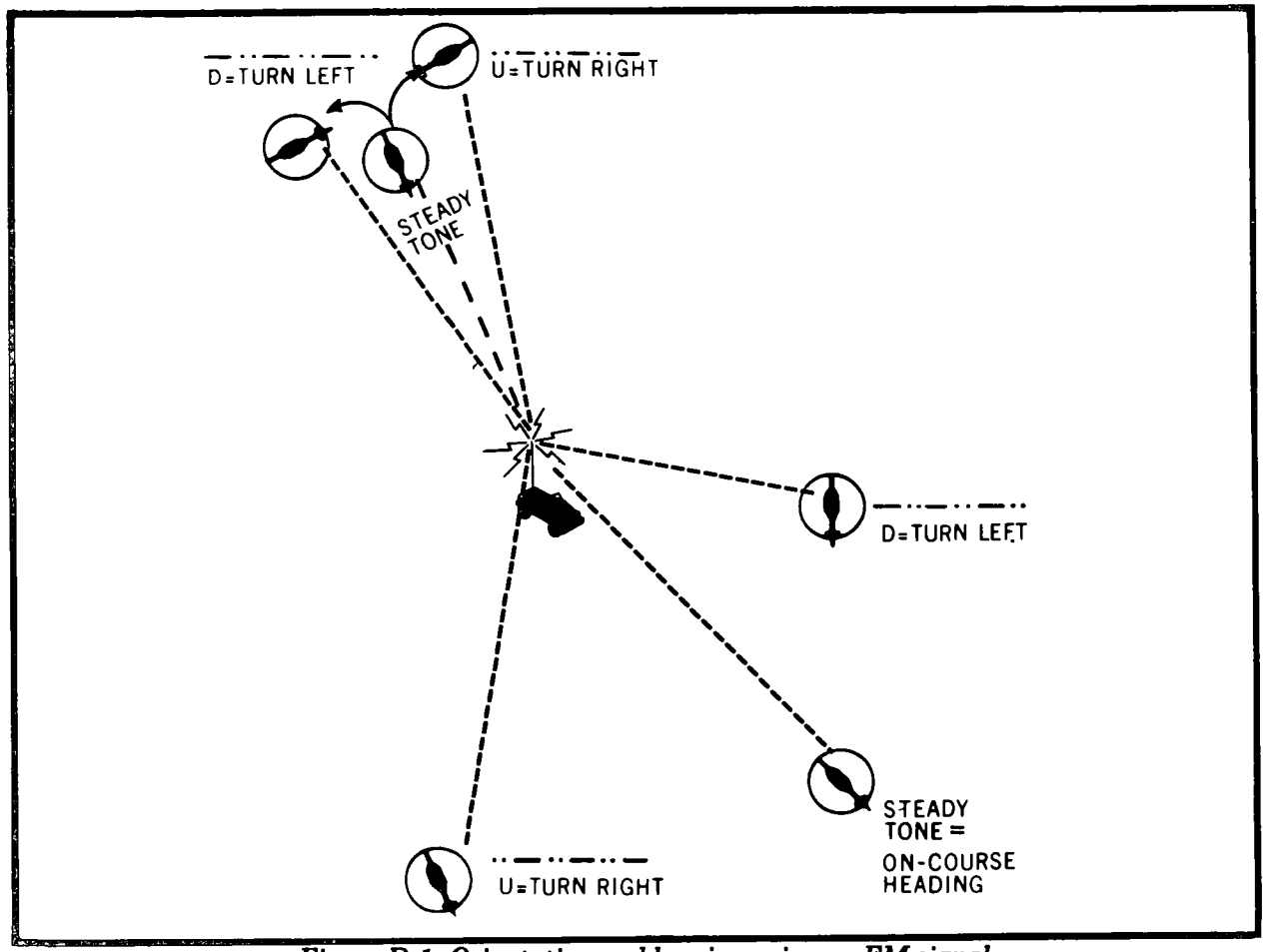


Figure D-1. Orientation and homing using an FM signal.

b. *Operation.*

(1) Set AN/ARC-44 for normal operation.

(2) Select the desired frequency and identify the station. Use authentication for positive identification.

(3) Instruct station operator to key his transmitter for periods of 30 seconds with 10-second pauses between transmissions.

(4) Set the COM-HOME switch to HOME position.

(5) Listen to the signal received.

(a) If a D (···) is heard, turn left.

(b) If a U (···) is heard, turn right.

(c) If a steady solid tone is heard, turn slightly off course and then respond to the D or U signal. The signal received will indicate the direction to the station. Turn in the direction which is indicated by the signal until a continuous tone is received. At this time the aircraft will be going toward the station.

c. *Station Passage.* To determine station passage, turn off course at 1- or 2-minute intervals. Turn each time in the same direction, listen to the signal, and turn back on course. A reversal of the signals will indicate station passage. Also, the station operator should be requested to inform the aviator when the aircraft passes over the station.

[redacted]

a. *General.* The AN/ARC-54 homing system requires a homing indicator (ID-48 or ID-453 omni indicator) and homing antenna system (towel rack) which allows the pilot to home on any signal transmitted within the set's frequency range of 30.00 to 69.95 MHz. Data provided by the homing facility is displayed visually on the course indicator, which is mounted on the instrument panel. Voice capability is provided in all three operating positions.

b. *Operation.*

(1) Establish contact with the station and specify a definite key period and pause period.

(2) Set the mode control to HOME.

(3) Set the SQUELCH control to CARR.

(4) Observe the deviation indicator. If sufficient signal strength is being received, the off flags on the course indicator will disappear. The position of the deviation indicator indicates the direction either left/right or on course to the station. A turn in the direction of the needle will cause it to center.

(5) If, upon tuning the station, the needle is centered, a turn should be made to insure that the system is functioning properly. Normal procedure should be followed as explained in (4) above if the needle deflects left or right during the turn.

(6) To determine station passage, turn off course at 1- to 2-minute intervals, each time in the same direction. Follow the vertical needle to return to an on-course indication (centered needle). Station passage will be indicated by a reversal of the vertical needle indication.

Note. Horizontal needle displays relative signal strength of station and should be used as a guide only for determining station passage.

D-3. AN/ARC-131 VOR/LOC

General. The AN/ARC-131 homing system requires the same equipment as the AN/ARC-54 (omni indicator and towel rack antenna) and employs the same operational procedures.

INDEX

	Paragraph	Page
A pattern	5-3	5-3
Common errors	5-3d	5-5
Absolute altitude	2-33	2-27
Accelerator error	2-5c(2)	2-4
Accelerations and decelerations (rotary wing)	4-28	4-29
ADF (automatic direction finder):		
NDB approach:		
Charts	19-6,20-10	19-7, 20-9
Clearance	19-22, 20-14	19-19, 20-15
Final	19-2d, 20-15	19-3, 20-15
Holding	19-14—19-22	19-14—19-19
	20-12—20-14	20-12—20-15
Beat frequency oscillator (BFO)	15-22b	15-17
Course interception	15-9, 15-10	15-6, 15-8
Homing	15-4	15-3
Indicator (radio compass)	15-3e	15-2
Loop operation	15-22—15-26	15-17—15-20
Maintaining a course	15-5	15-4
Missed approach	19-3	19-3
Orientation	15-4	15-3
Position fixing	15-8	15-5
Procedure turn	19-8—19-12	19-8—19-12
Receiver	15-2, 15-3	15-1, 15-2
Relative bearing	15-12	15-9
Station passage	15-6	15-5
Time and distance to station	15-11	15-8
Aeronautical charts (*See* Charts: Aeronautical.)		
Agonic line	2-5a	2-3
AIMS altimeter (counter-drum-pointer)	2-30c	2-22
Air navigation	6-1	6-1
Air navigation charts (*See* Charts: Aeronautical.)		
Airport surveillance radar (ASR)	22-3	22-2
Air route surveillance radar (ARSR)	22-2	22-2
Airspeed:		
Calibrated	2-36b, 10-5	2-29, 10-3
Computations	12-5	12-9
Constant	3-6	3-4
Indicated	2-36a, 10-5	2-29, 10-3
Indicator	10-5	10-3
True	2-36c, 10-5	2-29, 10-3
Airspeed indicator	2-34, 2-35, 10-5	2-28, 10-3
Construction	2-34	2-28
Operation	2-35	2-28
Airspeed settings:		
Fixed wing	4-3	4-2
Rotary wing	4-14	4-15
Air traffic control equipment (radar) (*See* Radar.)		
Air traffic control procedures (radar) (*See* Radar.)		
Air traffic shorthand symbols	App B	App B
Airways	14-11	14-13
Alternate source:		
Static pressure	2-27a	2-19
Vacuum	2-10	2-6
Altimeter, pressure:		
Construction	2-29	2-20
Definition	2-28	2-19
Effects of nonstandard temperatures and pressures	2-31	2-22
Errors	2-31a, b	2-23, 2-24
Reading	2-30	2-20
Setting	2-32	2-24
Altitude computations (CPU-26A/P)	12-17	12-10
Altitude, constant	3-7	3-4
Altitudes:		
Absolute	2-33c	2-27
Density	2-33e	2-27
Indicated	2-33a	2-27
Pressure	2-33b	2-27
True	2-33d	2-27
Ambiguity (loop)	15-23d	15-18
AN/ASN-86 Inertial Navigation Set	17-1	17-1
Accelerometer	17-3	17-2
Control/indicator unit	17-17	17-16
Coriolis effect and earth oblateness	17-9	17-9
Effect of a spherical rotating earth	17-7	17-5
Functions	17-12	17-11

	Paragraph	Page
Gyroscope and gimbal system	17-6	17-4
Gyrostabilized platform	17-14	17-14
Input data	17-13	17-14
Integrators	17-4	17-3
Navigation computer	17-15	17-15
Operator controls and indicators	17-16	17-16
Schuler pendulum and aircraft travel	17-8	17-7
System alinement	17-11	17-11
Total distance traveled	17-5	17-4
AN/ASN-128 Doppler Navigation Set	16-2	16-1
Controls, displays, and function	16-3	16-5
Data entry	16-6—16-19	16-8—16-14
Dead-reckoning navigation	16-20	16-14
Modes of operation	16-4	16-7
Power interruption procedures	16-21	16-15
Starting procedure	16-7	16-8
Angles	7-5	7-2
Apparent precession	2-8b	2-5
Approach (*See* ADF, ILS, VOR, and Radar.)		
Attenuation	13-10	13-7
Attitude, banking	3-19	3-12
Attitude indicator:		
Banking attitude	3-19	3-12
Electric (J-8)	2-15	2-8
Caging	2-17a,2-17c	2-11, 2-12
Construction	2-16	2-11
Errors	2-17	2-11
Operation	2-18	2-12
Positioning	2-16	2-11
Electric (Lear Model 4005G)	2-15	2-8
Navigation (ID-882)	2-15	2-8
Pitch attitude	3-11	3-6
Vacuum:		
Caging and uncaging	2-17c	2-12
Construction	2-16	2-11
Errors	2-17	2-11
Operation	2-18	2-12
Attitude instrument flying:		
Definition	1-2a	1-1
Power, pitch, and bank control	3-1	3-1
Aural null	15-23	15-17
Autorotations	4-27	4-29
Average groundspeed	11-7	11-6
Azimuth (*See* Measurement: Direction.)		
B pattern	5-4	5-5
Common errors	5-4c	5-6
Back course	16-42, 21-3a	16-26, 21-3
	21-9	21-13
Bank control	3-19	3-12
Common errors	3-25	3-16
To produce balanced straight flight	3-19	3-12
Trim	3-23	3-15
Bank indicating instruments:		
Attitude indicator	3-20	3-12
Heading indicator	3-21	3-13
Horizontal situation indicator	16-31	16-18
Turn-and-slip indicator	3-22	3-13
Vertical situation indicator	16-23	16-15
Barometric scale	2-30b	2-21
Beacons, marker	21-5	21-8
Beacon passage:		
ADF	15-6	15-5
FM homing	App D	App D
ILS	21-4a	21-6
Loop	15-24	15-19
Radio magnetic indicator	14-8b	14-8
VOR	14-10	14-13
Beat frequency oscillator	15-22b	15-17
Calibrated airspeed	2-36b, 10-5	2-29, 10-3
Cardinal points	7-12	7-6
Charts:		
Aeronautical:		
Photomaps	8-12	8-10
Sectional	8-10, 9-3b	8-9, 9-2
Tactical	8-13	8-10
World aeronautical	8-11, 9-3b	8-9, 9-2
Air navigation	8-1	8-1
Approach	20-2	20-1
Characteristics	8-4	8-2
Conformality	8-7d	8-6
Distortion	8-3	8-2
Graticule	8-5, 8-7	8-4, 8-5
Grid system	7-5	7-2
Lambert	8-7	8-5
Mercator	8-8	8-7
Polar stereographic	8-9a	8-7
Projections (*See* Projection.)		
Scales	8-2	8-1
Standard parallels	8-7b	8-5
Checkpoints (*See* Intersections.)		
Circles:		
Arcs	7-6b	7-4
Central angle	7-6c	7-4
Diameter	7-1	7-1
Great	7-6a	7-3
Radius	7-6c, 7-6d	7-4

	Paragraph	Page
Reference:		
Equator	7-8	7-4
Latitude	7-11a	7-5
Longitude	7-11b	7-5
Meridians	7-10	7-5
Parallels	7-7, 7-9	7-4, 7-5
Poles	7-7, 7-10	7-4, 7-5
Small	7-5, 7-6, 7-9	7-2, 7-3, 7-5
Clearance:		
Expected approach	20-7	20-8
Final approach	20-7	20-8
Holding	19-22	19-19
Missed approach	19-13	19-12
Shorthand	App B	App B
Straight-in	19-3	19-3
Transition/feeder	19-6, 19-7	19-7
Climbing turns:		
Fixed wing	4-10	4-10
Common errors	4-10b	4-10
Rotary wing	4-24	4-25
Common errors	4-24c	4-27
Climbs, straight (*See* Straight climbs (fixed and rotary wing).)		
Coarse azimuth pattern (TACAN)	18-3a	18-2
Co-channel interference (TACAN)	18-5d(2)	18-8
Codes (transponder)	22-13a	22-10
Command instrument system (CIS)	16-22—16-51	16-15—16-29
Components	16-22	16-15
Mode selector panel	16-33	16-19
Controls and functions	16-34—16-50	16-22—16-29
Operation	16-51	16-29
Compass:		
Magnetic	2-1	2-1
Radio	14-5	14-6
Compass turns:		
Fixed wing	4-11	4-11
Common errors	4-11d	4-12
Rotary wing	4-11, 4-21	4-11, 4-24
Common errors	4-11d	4-12
Compensator assembly	2-4	2-3
Components (AN/ARN-52 TACAN set)	18-6	18-9
Cone of confusion (azimuth)	18-5b	18-7
Constant airspeed	3-6	3-4
Control:		
Airspeed, constant	3-6	3-4
Altitude, constant	3-7	3-4
Attitude	3-8	3-4
Bank	3-19	3-12
Pitch	3-11	3-16
Power	3-4	3-3
Coordinates	7-5	7-2
Course:		
Magnetic	10-2b	10-2
Measuring	7-13	7-6
Plotting	9-4	9-3
Course indicator (VOR):		
Components	14-4	14-2
Course selector:		
Description	14-4a	14-4
Selecting a course	14-8a	14-8
Using the course reciprocal	14-10a	14-13
Deviation indicator (needle):		
Centered	14-4c(1)	14-5
Deflected	14-4c(2)	14-5
Description	14-4c	14-5
Sensitivity	14-4c(2)	14-5
Glide slope indicator	14-4d, 14-4e, 21-4,	14-6, 21-6
ID-883	2-23d	2-16
TO-FROM indicator	14-4b, 14-10	14-4, 14-13
Warning flags	14-4d	14-6
Course selector (VOR)	14-4a	14-4
CPU-26A/P dead-reckoning computer (grid side):		
Correcting the reported wind	12-30	12-22
Description	12-21, 12-22	12-15
Heading and airspeed computations	12-27	12-20
Heading and groundspeed computations	12-26	12-19
Sliding grid	12-22	12-15
Wind triangle	12-23, 12-30	12-17, 12-22
Wind velocity computations	12-28	12-20
CPU-26A/P dead-reckoning computer (slide rule face):		
Airspeed computation	12-15	12-9
Altitude computations	12-17	12-10
Density altitude computation	12-16	12-10
Description	12-3	12-1
Distance	12-9	12-8
Distance conversion	12-4	12-3
Drift correction	12-19	12-12
Fuel consumption calculations	12-11—12-14	12-7—12-9
Groundspeed computation	12-7	12-5
Indexes	12-3c, 12-10	12-3, 12-6
Off-course correction	12-18, 12-19	12-11, 12-12
Proportion	12-5	12-4
Radius of action (fixed base)	12-20	12-14

	Paragraph	Page
Ratio (*See* Proportion above.)		
Rule of 60	12-18	12-11
Scales	12-3a, b	12-1, 12-2
Time-distance computation	12-6	12-4
Time requirement	12-8	12-5
Cross-checking:		
Bank instruments	3-24	3-16
Definition	3-2	3-2
Pitch attitude instruments	3-17	3-11
Power instruments	3-10	3-6
Crosswind	11-2f, 11-6	11-4, 11-6
Current, electrical	13-3	13-3
Cycle	13-2b	13-2
Dead reckoning:		
Computers (*See* CPU-26A/P dead-reckoning computer.)		
Instruments	10-1b	10-1
Decelerations (rotary wing)	4-28	4-29
Degrees (angular)	7-6d	7-4
Density altitude	12-16	12-10
Descending turns:		
Fixed wing	4-10	4-10
Common errors	4-10b	4-10
Rotary wing	4-25	4-27
Common errors	4-25c	4-28
Descents, straight (fixed wing)	4-5	4-4
Descents, straight (rotary wing)	4-17	4-20
Deviation card	2-5b	2-3
Deviation errors, magnetic compass	2-5b	2-3
DF (direction finding) steers:		
Radar	22-5	22-3
Dip angle	2-3b	2-2
Directional gyro (*See Heading* indicator.)		
Distance conversion computation (CPU-26A/P)	12-2	12-1
Distance measuring equipment (DME) (TACAN)	18-1	18-1
Distance measurement (*See* Measurement: Distance.)		
Distortion	8-3	8-2
Dividers	9-2b	9-2
Double-the-angle course interception	14-12b	14-20
Drift corrections (*See also* Wind: Drift correction.):		
Application	11-5	11-5
Computation, CPU-26A/P	12-18, 12-19	12-11, 12-12
Course	11-3, 11-4	11-5
During tracking:		
ADF	15-5, 15-8	15-4, 15-5
VOR	14-9	14-10
Heading	10-2b, 11-2d, 11-3	10-2, 11-3, 11-5
Holding	19-16, 20-5c	19-14, 20-6
Procedure turn	19-12	19-10
Earth:		
Direction measuring	7-13	7-6
Distance	7-16, 7-17	7-8
Inclination	7-4	7-2
Measurement (*See* Measurement: Direction and Distance.)		
Position designation	7-5	7-2
Revolution	7-3	7-2
Rotation	7-2	7-1
Shape	7-1	7-1
Electric attitude indicator (Lear Model 4005G)	2-15	2-8
Electric heading indicator ID-567/ASN	2-23d	2-16
Electrically driven gyros	2-11	2-6
Equator	7-8, 7-9	7-4, 7-5
Erroneous navigational signal (TACAN)	18-5d	18-7
Errors:		
Acceleration	2-5c(2)	2-4
Bank control	3-25	3-16
Magnetic compass	2-5	2-3
Pitch attitude control	3-18	3-12
Establishing intersections (TACAN)	18-12	18-14
Expected approach clearance	20-4	20-4
FAA weather advisories	22-1, 22-17	22-1, 22-12
Feeder routes	19-5—19-7	19-6—19-7
Final approach (*See* ADF, VOR, ILS approaches.)		
Fine azimuth pattern (TACAN)	18-3b	18-3
Fixes (*See also* Position fixing.):		
ADF	15-8	15-5
Approach	19-2	19-2
VOR	14-11	14-15
Flight clearance (*See* Clearance: Flight.)		
Flight log	App C	App C
Float assembly (magnetic compass)	2-4	2-3
Flush type pitot-static system	2-25	2-17
FM homing	App D	App D
Frequency:		
Classifications	13-7	13-6
TACAN	18-2a, 18-14	18-1, 18-22
Front course	21-3c, 21-7	21-5, 21-12
Fuel consumption (CPU-26A/P)	12-12—12-14, App C	12-7—12-9, App C

	Paragraph	Page
Fuel consumption planning	App C	App C
GCA (*See* Ground-controlled approach.)		
Geographic North Pole	7-2	7-1
Glide slope (ILS)	21-4, 21-7	21-6, 21-12
Great circle	7-6a	7-3
Greenwich meridian	7-10	7-5
Grid system (charts)	7-5	7-2
Ground -controlled approach (GCA) (*See also* Radar: Air traffic control procedures: Approach control (GCA).):		
ASR (airport surveillance radar)	22-3	22-2
PAR (precision approach radar)	22-9e	22-8
Groundspeed checks (TACAN)	18-11	18-14
Ground weather radar	22-15—22-17	22-12
Gyros:		
Definition	2-6	2-5
Electrically driven	2-11	2-6
Heading indicator	2-12	2-7
Instrument power source	2-9—2-11	2-6
Mode of operation	2-13	2-8
Mountings	2-7	2-5
Vacuum driven	2-10	2-6
Gyroscopic properties:		
Precession	2-8b	2-5
Rigidity in space	2-8a	2-5
Heading:		
Compass	2-1, 10-2b	2-1, 10-2
Drift and groundspeed	11-2d	11-3
Magnetic	2-1, 10-2b	2-1, 10-2
Track and groundspeed	11-2e	11-3
True	10-2	10-2
Heading and airspeed computations (CPU-26A/P)	12-27	12-20
Heading and groundspeed computations	12-26	12-19
Heading indicator:		
Banking or turning	3-19	3-12
Course indicator ID-883	2-23d	2-16
Electric ID-567/ASN	2-23d	2-16
Magnetic compass (*See* Magnetic compass.)		
Radio magnetic:		
ID-250/ARN	2-22	2-14
ID-998/ASN	2-22, 2-27	2-14, 2-18
Vacuum	2-15	2-8
Headwind	11-2f, 11-6	11-4, 11-6
High frequency propagation	13-12	13-8
Holding:		
ADF:		
Airspeeds	20-4	20-4
Clearances and reports	20-11	20-11
Course	20-5	20-5
Descent in pattern	20-6	20-7
Drift correction	19-21, 20-5c	19-18, 20-6
Entry	20-12	20-12
VOR:		
Airspeed	19-17, 20-4c	19-16, 20-5
Drift correction	19-21, 20-5c	19-18, 20-6
Entry	19-19, 20-12	19-16, 20-12
Stacking	19-23	19-20
Timing	19-16, 20-5d	19-14, 20-6
Homing:		
ADF	15-4	15-3
FM	App D	App D
Loop	15-24	15-19
Horizon bar, operation	2-16	2-11
Horizontal situation indicator (HSI)	16-31	16-18
Controls and indicators	16-32	16-18
Identification (TACAN station)	18-2b	18-2
IFR flight planning	App C	App C
ILS (*See* Instrument landing system.)		
Inaccurate determination of station passage	18-10	18-13
Inclination	7-4	7-2
Indicated airspeed	2-36a, 10-5	2-29, 10-3
Indicated altitude	2-33a	2-27
Indicator:		
Airspeed	2-34, 2-35	2-28
Altimeter	2-28—2-30	2-19—2-22
Attitude	2-14	2-8
Course, indicator ID-883	2-23d	2-16
Heading	3-21	3-13
Navigation attitude (ID-882)	2-15	2-8
Slaved gyro magnetic (*See* Slaved gyro magnetic heading indicators.)		
Turn-and-slip	2-19	2-12
Vertical speed	2-37	2-29
Instantaneous vertical speed indicator (IVSI)	2-41	2-30
Instrument approach procedure (*See also* Approach: Instrument and ILS.):		
Holding	19-14—19-22	19-14—19-20
Missed approach	19-13	19-12
Procedure turns	19-8—19-12	19-8—19-12
Straight-in	19-3	19-3
Transitions/feeders	19-5, 19-6	19-6, 19-7

	Paragraph	Page
Instrument flying (*See* Altitude instrument flying.)		
Instruments indicating bank attitude:		
Attitude indicator	3-20	3-12
Heading indicator	3-21	3-13
Turn-and-slip indicator	3-22	3-13
Ball	3-22b	3-14
Turn needle	3-22a	3-13
Instruments indicating pitch attitude:		
Airspeed indicator	3-15	3-10
Altimeter	3-13	3-8
Attitude indicator	3-12	3-7
Vertical speed indicator	3-14	3-9
Instrument landing system (ILS):		
Approach procedures:		
Charts	19-6, 21-6	19-7, 21-10
Clearance	21-6	21-10
Final	21-7, 21-8	21-12
Holding	19-14—19-23, 21-7	19-14—19-21, 21-12
Missed approach	19-13, 21-8e	19-12, 21-13
Procedure turn	19-4, 19-8—19-12a,	19-5, 19-8—19-12
Ground components	21-2	21-1
Instruments, navigation:		
Airspeed indicator	10-5	10-3
Course indicator, ID-453(VOR)	14-4	14-2
Dead reckoning	10-1	10-1
Heading indicator (gyro)	10-3	10-3
Magnetic compass	10-2	10-2
Radio magnetic indicator (RMI)	14-5, 15-3e	14-6, 15-2
Instruments, power	3-5	3-3
Instrument takeoff:		
Fixed wing	4-3	4-2
Common errors	4-3c	4-2
Rotary wing	4-14	4-15
Common errors	4-14d	4-17
Intercardinal points	7-12	7-6
Interception, course:		
ADF	15-9, 15-10	15-6, 15-8
Double-the-angle	14-12b	14-20
Loop	15-25	15-19
RMI	15-9, 15-10	15-6, 15-8
VOR	14-12	14-18
Interception of TACAN arcs	18-13c	18-19
Intersections	14-11, 15-8	14-13, 15-5
Isogonic lines	2-5a	2-3
Kollsman window	2-30b, 2-33	2-21, 2-27
Lag: Vertical speed indicator	2-39	2-30
Lambert conformal projection	8-7	8-5
Latitude	7-11a	7-5
Level turns:		
Fixed wing	4-6	4-6
Common errors	4-6e	4-7
Rotary wing	4-19	4-22
Common errors	4-19b	4-23
LF/MF propagation	13-11	13-8
Light systems (ILS)	21-2b(6)	21-2
Line-of-sight transmission	13-13	13-8
Lines:		
Agonic	2-5a	2-3
Isogonic	2-5a	2-3
Localizer, ILS:		
Back course	21-9	21-13
Blue sector	21-3	21-3
Front course	21-7	21-12
Location and signal	21-3	21-3
Needle deflection	21-3c	21-5
Receiver	21-3b	21-4
Tracking	21-3c	21-5
Yellow sector	21-3	21-3
Lock-on (TACAN)	18-5d(1)	18-7
Loop (ADF):		
Ambiguity	15-23d	15-18
Beacon passage	15-24b	15-19
Homing	15-24	15-19
Null	15-23a	15-17
Orientation	15-23	15-17
Time and distance	15-26	15-20
Tracking	15-25	15-19
Low frequency (*See* LF/MF progagation.)		
Loxodromic curve	7-15	7-7
Lubber line	2-4	2-3
Magnetic:		
Compass	2-1, 10-2	2-1, 10-2
Compensator assembly	2-4	2-3
Construction	2-4	2-3
Errors:		
Deviation	2-5b	2-3
Magnetic dip	2-5c	2-3
Acceleration	2-5c(2)	2-4
Magnetic field	2-5c(4)	2-4
Northerly turning	2-5c(1)	2-3
Constructional compensation	2-5c(5)	2-4
Oscillation	2-5c(3)	2-4
Variation	2-5a	2-3

	Paragraph	Page
Float assembly	2-4	2-3
Lubber line	2-4	2-3
Swinging	2-5b	2-3
Course	10-2b	10-2
Deviation	2-5b	2-3
Direction	10-1	10-1
Fields	2-3, 2-5c(4)	2-2, 2-4
Heading	11-2f	11-4
Indicator, radio (*See* Radio magnetic indicator.)		
Lines of force	2-2	2-2
North Pole	2-5a	2-3
Poles, location	2-3a	2-2
Variation	2-5a	2-3
Maintaining arcs (TACAN)	18-13d	18-20
Maneuvers, basic instrument:		
Fixed wing	4-1	4-1
Proficiency	5-1	5-1
Rotary wing	4-13	4-15
Map, video	22-2b	22-2
Manual loop procedures	15-22	15-17
Map (*See* Charts.)		
Marker	21-5	21-8
Mean meridian	7-13	7-6
Measurement (*See also* PLU-2/C plotter.):		
Direction:		
Bearing (relative)	15-12	15-9
Cardinal points	7-12	7-6
Compass rose	7-13	7-8
Course	7-14	7-7
Degree	9-3c	9-3
Geographical	7-12, 7-13	7-6, 7-8
Radial	14-8a	14-8
Track	11-2b	11-3
Distance:		
Angular	7-6d	7-4
Arcs	7-6b	7-4
Degrees	7-6b	7-4
Dividers	9-2b	9-2
Great circle	7-6a	7-3
Linear	7-6d	7-4
Radius	7-6c	7-4
Scale	8-2	8-1
Statute and nautical miles	7-16	7-8
TACAN	18-4	18-5
Units	7-16	7-8
Position (geographical)	7-5—7-11	7-2—7-5
Measuring	7-16	7-8
Mercator chart	8-8	8-7
Meridians:		
Greenwich (prime)	7-10	7-5
Longitude	7-11b	7-5
Middle marker	21-5c	21-8
Miles:		
Nautical	7-16c	7-8
Statute	7-16b	7-8
Minimum authorized altitude	19-6a(3), 19-11	19-7, 19-10
Minimum enroute altitude (MEA)	22-7c, App C	22-4, App C
Minimum obstruction clearance altitude (MOCA)	22-7c	22-4
Missed approach	19-13, 20-9, 20-15c	19-12, 20-9, 20-16
Modulation:		
Amplitude	13-5	13-3
Frequency	13-5	13-3
Monitor: Nonradar	22-10	22-8
Nautical mile	7-16c	7-8
Navigation:		
Aids (*See* Radio: Aids to navigation.)		
Air	6-1	6-1
Attitude indicator (ID-882)	2-15	2-8
Charts (*See* Charts.)		
Dead reckoning	10-1a	10-1
Instruments (*See* Instruments, navigation.)		
TACAN	18-9	18-13
Needle (VOR) (*See* VOR: Course indicator.)		
Nonstandard atmospheric pressure	2-31	2-22
Nonstandard temperature	2-31	2-22
Northerly turning error	2-5c(1)	2-3
North Pole:		
Geographic	2-5a, 7-2, 7-7	2-3, 7-1, 7-4
Magnetic	2-5a	2-3
NOTAMS	App C	App C
Null	15-22	15-17
Off-course correction (drift) (CPU-26A/P)	12-18, 12-19	12-11, 12-12
Omnidirectional range (*See* VOR.)		
Orbit	7-3	7-2
Orientation:		
ADF	15-4	15-3
FM homing	App D	App D
Loop	15-23	15-17
VOR	14-8	14-8
Oscillation error	2-5c(3)	2-4
Outer marker	21-5b	21-8
Parallels	7-11c	7-5
Pattern A	5-3	5-3

	Paragraph	Page
Pattern B	5-4	5-5
Photomaps	8-12	8-10
Phraseology, radio	22-14	22-11
Pitch:		
Attitude	3-11	3-6
Control	3-11	3-6
Cross-checking of instruments	3-2	3-2
Trim	3-3	3-3
Pitch indicating instruments:		
Airspeed indicator	3-15	3-10
Altimeter	3-13	3-8
Attitude indicator	3-12	3-7
Vertical speed indicator	3-14	3-9
Pitot-static system	2-25	2-17
Impact pressure	2-26	2-18
Static pressure	2-27	2-18
Pitot tube	2-26	2-18
Plotter (*See* PLU-2/C plotter.)		
Plotting (position)	8-6c	8-5
PLU-2/C plotter	9-2c, 9-3	9-2
Polar stereographic projection	8-9	8-7
Position fixing:		
ADF	15-8	15-5
In holding pattern	19-7, 20-5d, 20-13	19-7, 20-6, 20-12
VOR	14-11	14-15
Position reports	19-22	19-19
Power:		
Airspeed settings, rotary wing	4-13	4-15
Changes	3-6	3-4
Control	3-4	3-3
Definition	3-4	3-3
Gyroscopic instrument, source	2-9—2-11	2-6
Instruments	3-5	3-3
Precession (gyroscopic)	2-8b	2-5
Apparent	2-8b(2)	2-6
Real	2-8b(1)	2-6
Precision approach radar (PAR)	22-9e	22-8
Preflight check (TACAN)	18-8	18-12
Pressure:		
Altimeter	2-28	2-19
Construction	2-29	2-20
Definition	2-28	2-19
Reading	2-30	2-20
Setting	2-32	2-24
Altitude	2-33b	2-27
Counter-drum-pointer (AIMS)	2-30c	2-22
Density	2-33e	2-27
Differential	2-25	2-17
Nonstandard effect	2-28	2-19
Prime meridian (Greenwich)	7-10, 7-11	7-5
Procedure turns:		
Adjustment for wind	19-10	19-10
Area	19-11	19-10
Minimum altitude	19-11	19-10
Teardrop	19-9c	19-9
Turning rate	19-12	19-10
Proficiency maneuvers (fixed wing):		
Pattern A	5-3	5-3
Common errors	5-3d	5-5
Pattern B	5-4	5-5
Common errors	5-4c	5-6
Vertical S and S-1	5-2	5-1
Common errors	5-2d	5-2
Projection:		
Lambert	8-7	8-5
Mercator	8-8	8-7
Modified polar stereographic	8-9	8-7
Polar stereographic	8-9	8-7
Properties of gyroscopic action	2-8	2-5
Radar:		
Air traffic control procedures:		
Approaches (ASR and PAR)	22-3, 22-9	22-2, 22-7
Arrival control	22-8b	22-5
Departure control	22-8a	22-4
Enroute control	22-7	22-4
Handoff	22-6	22-3
Monitor service	22-10	22-8
Target identification	22-5	22-3
Transfer of control	22-6	22-3
Transitions	22-8b	22-5
Phraseology	22-14	22-11
Transition/feeder	19-6, 19-7	19-7
Transponder	22-13	22-10
Vectors	22-7b	22-4
Weather: Ground	22-15	22-12
Radial	14-8a	14-8
Radiated test signal (VOT)	14-17	14-25
Radio:		
Cycle	13-2b	13-2
Frequencies	13-2c, 13-7—13-13	13-2, 13-6—13-8
Frequency modulation	13-5b	13-5
Principles	13-4—13-13	13-3—13-8
Receivers (*See also* Receivers.)	13-6	13-5
Signal propagation	13-8—13-13	13-6—13-8
Transmitters	13-5	13-3
Wavelengths	13-2d	13-2
Waves	13-2, 13-4	13-1, 13-3
Radio compass indicator (ADF)	14-5	14-6
Radio magnetic indicator (RMI)	14-5, 15-3e	14-6, 15-2
Radius	7-6c	7-4

	Paragraph	Page
Radius of action (CPU-26A/P)	12-20	12-14
Ratio and proportion (CPU-26A/P)	12-3, 12-5	12-1, 12-4
Real precession	2-8b(1)	2-6
Receivers:		
ADF (ARN-59)	15-2, 15-3	15-1, 15-2
Checks	14-14–14-20	14-24–14-27
Dual	14-18	14-28
Glide slope	21-4b	21-6
Localizer	21-3b	21-4
Marker beacon	21-5	21-8
Radio principles	13-6	13-5
VOR	14-11, 14-13	14-15, 14-22
Recoveries from unusual attitudes:		
Fixed wing	4-12	4-12
Common errors	4-12g	4-15
Rotary wing	4-26	4-28
Common errors	4-26e	4-29
Reference circles (*See* Circles: References.)		
References	App A	App A
Relative bearing:		
Course interception	15-19, 15-20	15-14, 15-15
Homing	15-14	15-11
Maintaining a course	15-16, 15-17	15-12, 15-13
Orientation	15-13	15-10
Position fixing	15-18	15-14
Station passage	15-15	15-11
Time and distance	15-21	15-16
Revolution	7-3	7-2
Rhumb line	7-15	7-7
Rigidity in space (gyroscopic)	2-8a	2-5
RMI (*See* Radio magnetic indicator.)		
Rose, compass	7-13	7-6
Rotation	7-2	7-1
Route selection	App C	App C
Runway visual range (RVR)	20-2b(12)	20-3
Safety instrument approach	19-24	19-22
S and S-1 maneuvers (*See* Proficiency maneuvers (fixed wing).)		
Scales:		
Chart	8-2	8-1
CPU-26A/P computer	12-3a, 12-3b	12-1, 12-2
Sectional charts	8-10	8-9
Sectors:		
Air traffic control	22-6	22-3
Holding pattern entry	20-12	20-12
ILS localizer, color coded signal	21-3a	21-3
Servo failure	4-29	4-30
Signal patterns:		
Glide slope, ILS	21-4	21-6
Localizer, ILS	21-3a	21-3
Marker beacon	21-5	21-8
VOR	14-2	14-1
Signal propagation, radio	13-8—13-14	13-6—13-8
Skip distance	13-9	13-7
Skip zone	13-9	13-7
Slaved gyro compass system:		
AN/ASN-13 and J-2 compass systems operation	2-22	2-14
Components	2-23	2-16
Slaved gyro magnetic heading indicators:		
Course indicator ID-883	2-23d	2-16
Electric ID-567/ASN	2-23d	2-16
Radio magnetic ID-250/ARN	2-22	2-14
Radio magnetic ID-998/ASN	2-22	2-14
Small circles	7-5, 7-6	7-2, 7-3
Sphere	7-1, 7-6	7-1, 7-3
Spheroid	7-1	7-1
Standard instrument departures (SID)	22-8, App C	22-4, App C
Standard of atmosphere, US	2-28	2-19
Standard terminal arrival routes (STARs)	19-5—19-7	19-6—19-7
Static, radio	13-11	13-8
Station passage, VOR	14-10b	14-13
Statute mile	7-16b	7-8
Steep turns:		
Fixed wing	4-8	4-8
Common errors	4-8b	4-9
Rotary wing	4-22	4-24
Common errors	4-22b	4-24
Straight-and-level flight:		
Fixed wing	4-4	4-3
Common errors	4-4f	4-4
Rotary wing	4-16	4-19
Common errors	4-16d	4-20
Straight climbs and descents (fixed wing)	4-5	4-4
Common errors	4-5i	4-5
Straight climbs (rotary wing)	4-15	4-17
Common errors	4-15e	4-18
Straight descents (rotary wing)	4-17	4-20
Common errors	4-17d	4-21
Straight-in:		
Approach	19-3	19-3
Clearance	19-3	19-3
Landing	19-3, 20-8	19-3, 20-9
Surveillance radar	22-3	22-2
Swinging the magnetic compass	2-5b	2-3

	Paragraph	Page
Table 2-1: Standard pressure and temperatures at 1,000-foot intervals		2-21
TACAN (AR/ARN-52 set):		
Arcs	18-13	18-16
Components	18-6	18-9
Establishing intersections	18-12	18-14
Fixing intersections	18-12	18-14
Groundspeed checks	18-11	18-14
Inaccurate determination of station passage	18-10	18-13
Navigational procedures	18-9	18-13
Tuning	18-6	18-9
Tactical instrument flight:		
Aids, navigational	23-9c(2)	23-9
Altitudes	23-8, 23-13	23-6, 23-14
Approaches	23-9c(1)	23-8
Communications	23-11d(5)	23-12
Course line, determining the	23-12	23-12
Definition	23-5	23-2
Employment, principles of	23-7	23-3
Flight clearance	23-7b	23-4
Flight-following	23-7b	23-4
Threat avoidance	23-7a	23-4
Flight routes selection	23-9a, 23-9b	23-7
Navigation, radio and dead reckoning	23-13b(1), (2),(3)	23-15, 23-16
Planning:		
Preflight	23-11	23-10
Takeoff	23-14	23-19
Prerequisites	23-2	23-1
Procedures:		
Approach	23-15	23-25
Missed	23-17	23-31
Safety zone, construction of	23-15b(2)	23-28
Straight-in	23-15b	23-27
Terminal	23-15a	23-25
Emergency	23-18	23-33
Aircraft deficiency	23-18c	23-34
Air defense	23-18a	23-33
Radio navigational aids, loss of	23-18b	23-34
Holding	23-16	23-31
Threat	23-3, 23-7a	23-2, 23-4
Training	23-6, 23-19, 23-20	23-3, 23-35
Tailwind	11-2f, 11-6	11-4, 11-5
Takeoff, instrument:		
Fixed wing	4-3	4-2
Rotary wing	4-14	4-15
Teardrop turn	19-9c	19-9
Time-distance computations (CPU-26A/P)	12-6	12-4
Time-distance to beacon:		
ADF	15-11	15-8
VOR	14-13	14-22
Timed turns:		
Fixed wing	4-9	4-9
Common errors	4-9e	4-10
Rotary wing	4-23	4-24
Common errors	4-23f	4-25
TO-FROM indicator (VOR)	14-4b	14-4
Tracking:		
ADF	15-4	15-3
ILS localizer	21-3	21-3
Loop	15-25	15-19
VOR	14-9	14-10
Track interception (*See* Interception, track.)		
Traffic control centers, air route-	22-2	22-2
Transmissometer	21-2b(2)	21-2
Transmitter:		
ADF	15-1	15-1
ILS glide slope	21-4	21-6
ILS localizer	21-3	21-3
VOR	14-2	14-1
Transponder, use of	22-13	22-10
Triangle of velocities	12-25, 12-30	12-18, 12-22
Trim	3-3	3-3
Bank attitude	3-23	3-15
Pitch attitude	3-11	3-6
True airspeed	2-36c, 10-5, 11-6, App C	2-29, 10-3, 11-6, App C
True altitude	2-33d	2-27
Tuning (AN/ARN-52 TACAN set)	18-6	18-9
Turn-and-slip indicator	2-19	2-12
Ball	2-21	2-13
Turn needle	2-20	2-13
Turns:		
Banking (*See* Bank control.)		
Climbing (rotary wing)	4-24	4-25
Common errors	4-24c	4-27
Climbing and descending (fixed wing)	4-10	4-10
Common errors	4-10b	4-10
Compass:		
Fixed wing	4-11	4-11
Common errors	4-11d	4-12
Rotary wing	4-21	4-24
Common errors	4-21	4-24
Descending (rotary wing)	4-25	4-27
Common errors	4-25c	4-28
Level:		
Fixed wing	4-6	4-6
Common errors	4-6e	4-7
Rotary wing	4-19	4-22
Common errors	4-19b	4-23

	Paragraph	Page
Procedure (*See* Procedure turns.)		
Steep:		
Fixed wing	4-8	4-8
Common errors	4-8b	4-9
Rotary wing	4-22	4-24
Common errors	4-22b	4-24
Timed:		
Fixed wing	4-9	4-9
Common errors	4-9e	4-10
Rotary wing	4-23	4-24
Common errors	4-23f	4-25
To headings (gyro):		
Fixed wing	4-7	4-7
Common errors	4-7c	4-8
Rotary wing	4-20	4-23
Common errors	4-20b	4-23
UHF propagation	13-13	13-8
Units (measurement)	7-16	7-8
Unusual attitudes and recoveries:		
Fixed wing	4-12	4-12
Common errors	4-12g	4-15
Rotary wing	4-26	4-28
Common errors	4-26e	4-29
Upwind	11-1, 11-4h	11-1, 11-5
Vacuum attitude indicator (*See* Attitude indicator, vacuum.)		
Vacuum drive gyros	2-10	2-6
Vacuum gage	2-10	2-6
Vacuum source	2-10	2-6
Vacuum system:		
Gage	2-10	2-6
Operating pressures	2-10	2-6
Source	2-10	2-6
Variation, magnetic	2-5a	2-3
Vectors:		
Radar	22-1b(5)	22-2
Wind	12-23	12-17
Velocities, triangle	12-23, 12-24, 12-30	12-17, 12-18, 12-22
Velocity, wind (*See* Wind: Direction and speed.)		
Vertical S and S-1	5-2	5-1
Vertical situation indicator (VSI)	16-23—16-29	16-15—16-17
Controls and indicators	16-30	16-17
Vertical speed indicator	2-37	2-29
Adjustment	2-40	2-30
Construction	2-37	2-29
IVSI	2-41	2-30
Lag	2-39	2-30
Operation	2-38	2-30
VHF omnidirectional range (*See* VOR.)		
VHF propagation	13-13	13-8
Victor airways	14-11	14-13
Voice communications (*See* Radio: Communications.)		
Voice procedures (*See* Radio: Communications.)		
VOR (VHF omnidirectional range):		
Approach:		
Charts	19-6, 20-2	19-7, 20-1
Clearance	20-4	20-4
Final	20-7	20-8
Holding	19-14—19-23, 20-5	19-14—19-21, 20-5
Missed approach	19-13, 20-9	19-12, 20-9
Procedure turn	19-8—19-12	19-8—19-12
Transmitter	14-2	14-1
Warning flags:		
Course indicator (VOR)	14-4	14-2
Glide slope	14-4d	14-6
Vertical situation indicator (VSI)		
Wavelength	13-2d	13-2
Wave, radio	13-2a, 13-4	13-1, 13-3
Wave, transmission	13-2	13-1
Weather:		
Flight planning	App C	App C
Radar: Ground	22-15—22-17	22-12
Static	13-11	13-8
Wind:		
Crosswind	11-2f, 11-6	11-4, 11-6
Direction and speed	11-1	11-1
Downwind	11-4	11-5
Drift	11-2b, 11-4	11-3, 11
Drift correction (*See* Drift correction.)		
Headwind	11-2f, 11-6	11-4, 11-6
Tailwind	11-2f, 11-6	11-4, 11-6
Triangle	12-23, 12-24, 12-30	12-17, 12-18, 12-22
Upwind	11-4	11-5
Vectors	12-23	12-17
Velocity computation (CPU-26A/P)	12-28	12-20
World aeronautical chart	8-11	8-9

By Order of the Secretary of the Army:

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